AMERICAN SOCIETY

FOR

TESTING MATERIALS

AFFILIATED WITH THE
INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS

PROCEEDINGS

OF THE

SIXTEENTH ANNUAL MEETING

Held at Atlantic City, New Jersey
June 24-28, 1913

VOLUME XIII

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SUMMARY OF THE PROCEEDINGS OF THE SIXTEENTH ANNUAL MEETING.

ATLANTIC CITY, N. J., JUNE 24-28, 1913.

THE SIXTEENTH ANNUAL MEETING OF THE AMERICAN SOCIETY FOR TESTING MATERIALS was held at the Hotel Traymore, Atlantic City, N. J., on June 24–28, 1913. The total registered attendance at the meeting, including 85 ladies and 49 guests, was 477.

The following members were present or represented at the meeting:

A

Abraham, Herbert,
Ralph L. Shainwald, Jr.
Aertsen, Guilliaem.
Aiken, W. A.
Ajax Metal Company,
G. H. Clamer.
Akin, Thomas R.
Allen, A. W.
Allen, Irving C.
Aluminate Patents Company,
E. L. Conwell.
American Brass Company,
W. H. Bassett.
American Bridge Company,
C. G. E. Larsson.
American Electric Railway Engineering Association,
Norman Litchfield.
American Foundrymen's Association,
Richard Moldenke.
American Locomotive Company,
S. V. Hunnings.
American Steel and Wire Company,
Edwin H. Peirce.
American Vulcanized Fibre Company,
Charles Almy, Jr.
Anderson, Louis, Jr.
Armstrong, T. P.
Ashton, Ernest.

B

Backert, A. O.
(*Iron Trade Review*).
Bacon, Charles V.
Baldwin Locomotive Works, The.
H. V. Wille.
Barbey, Jacob W.
Barrett Manufacturing Company,
W. S. Babcock
Barrier, Edward A.
Bates, P. H.
Bausch and Lomb Optical Company,
H. E. Howe.
Baxter, Florus R.
Beale, Horace A., Jr.
Berry, H. C.
Bethlehem Steel Company,
E. O'C. Acker.
Birkinbine, John.
Blackburn, W. T.
Blackmer, L. G.
Blair, Will P.
Blakeley, Abraham G.
Bleininger, A. V.

Boughton, Everett W.
Boyer, E. D.
Boylston, H. M.
Boynton, C. W.
Boynton, Henry C.
Bragg, C. T.
Braine, L. F.
Brobston, Joseph.
Brown, John G.
Browne, D. B.
Browne, Vere.
Brunner, John.
Bureau of Construction and Repair, U. S. N.,
Emory Scott Land.
Bureau of Steam Engineering, U. S. N.,
Gustav Kaemmerling.
Burgess, Charles F.
Burrows, Charles W.

C

Cain, John R.
Calumet Steel Company,
A. S. Hook.
Cambria Steel Company,
E. F. Kenney.
Camden Forge Company,
W. D. Kerlin.
Campbell, William.
Capp, John A.
Carnegie Institute, The,
Francis Michael McCullough.
Carnegie Steel Company,
C. F. W. Rys.
Carpenter, Rolla C.
Carpenter Steel Company, The,
J. H. Parker.
Carter Iron Company,
R. A. Carter.
Central Iron and Steel Company,
Robert H. Irons.
Chamberlain, G. D.
Charls, G. H.,
G. F. Ahlbrandt.
Christie, Alexander J.
Churchill, Charles S.
Cobb, Ernest B.
Coe, Robert.
Cohen, A. B.
Colby, J. A.
Colorado Fuel and Iron Company,
Jacob Cambier.
Compressed Gas Manufacturers Association,
H. E. Sturcke.
Conard, W. R.
Condit, E. A., Jr.
Conn, Charles F.
Conradson, P. H.
Consolidated Rosendale Cement Company,
William C. Morton.
Cook, Oscar W.
Corse, W. M.
Cowan, William A.
Cromwell, O. C.
Cushman, Allerton S.

D

Dalton, P. J.
Dannerth, Frederic.
Davis, Nathan H.
De Knight, Edward W.
Devries, Ralph P.
Dewey, Bradley.
Diller, H. E.
Dixon Crucible Company,
Joseph,
Malcolm McNaughton.
Douty, D. E.
Drew, Harry.
Dunn, B. W.
Dunn, F. B.
Dunn, W. R.

E

Eastern Steel Company,
Walter S. Merkel.
Edgerly, Daniel W.
Emley, Warren E.
Engineering Record,
E. J. Mehren.

Enright, Bernard.
Epstein, Harry M.
Evans, S. M.,
J. A. Schaeffer.

F

Ferguson, Lewis R.
Fireman, Peter.
Fleming, William R.
Force, H. J.
Forrest, C. N.
Fowler, George L.
Frankfurter, P. W.
Franklin Manufacturing Company,
H. H.,
J. H. Nead.
Franklin Steel Company,
Edward E. Hughes.
Froehling and Robertson,
Henry C. Froehling.
Fulweiler, W. Herbert.

G

Gaines, Richard H.
Gano, William P.
Gardner, Henry A.
General Electric Company,
J. A. Capp.
General Motors Company,
K. W. Zimmerschied.
Gibboney, James H.
Gibbs, A. W.
Gifford, A. McK.,
F. C. Woodside.
Glasgow Iron Company,
James P. Roe.
Godley, George McM.
Goldbeck, Albert T.
Goodell, John M.
Gould, W. S.
Greene, Hermann L.
Greenman, Russell S.
Gregory, E. D.
Griffith, R. E.
Griswold, H. C.
Gulick, Henry, Jr.
Gutta Percha and Rubber Manufacturing Company, The,
W. E. Campbell.

H

Hall, Ellis B.
Hall, John H.
Hamburger, Samuel.
Harding, W. H.
Hartranft Cement Company, William G.,
William G. Hartranft.
Hartwell, Stephen Warren.
Hartzell, H. S.
Hatt, William K.
Hay, J. T.
Heath, A. M.
Heckel, G. B.
Hemstreet, George P.
Henry, John A.
Hibbard, Henry D.
Hilles, Raymond W.
Holst, J. L.
Hooker, A. H.
Hopkins, George A.
Howard, L. E.
Humphrey, Richard L.
Hunnings, S. V.
Hunt and Company, Robert W.,
Robert W. Hunt.

I

Ickes, Elwood T.
Illinois Steel Company,
P. E. Carhart.
Ingalls, F. P.
Iron Age, The,
A. I. Findley.

J

Jeffers, John M.
Job, Robert.
Johnson, Arthur M.
Jones and Laughlin Steel Company,
Jesse J. Shuman.
Joseph, J. G.,
W. H. Woodcock.

K

Karr, C. P.
Kelley, F. W.
Kenney, E. F.
Kenney, Lewis Hobart.
Kershaw, William H.
Kiefer, H. E.
Kinney, William M.
Koch, George B.
Kohr, D. A.

L

Lanza, Gaetano.
Larned, E. S.
Larsson, C. G. E.
Lawson, Thomas R.
Leech, J. O.
Lehigh Valley Railroad Company,
Stewart E. Printz.
Lesley, Robert W.
Lewis, Archer W.
Light, Charles P.
Linder, Oscar.
Little, Incorporated, A. D.,
Hervey J. Skinner.
Lober, J. B.
Lowe Brothers Company, The,
D. A. Kohr.
Loweth, Charles F.
Lucas and Company, John,
Leo P. Nemzek.
Lunn, Charles A.
Lynch, T. D.

M

MacFarland, H. B.
Mackenzie, Kenneth Gerard.
Macnichol, Charles.
MacPherran, R. S.
Marburg, Edgar.
Marsh, C. P.
Marston, A.
Masters, Frank M.
Masury and Son, John W.,
F. P. Ingalls.
McCready, Ernest B.
McDonnell, M. E.
McLeod, Norman C.
McNaugher, D. W.
Meade, Richard K.
Metal Industry, The,
L. J. Krom.
Midvale Steel Company,
G. Aertsen.
Miner, Joshua L.
Missouri Pacific Railway Company,
O. F. Reynolds.
Moisseff, Leon S.
Moldenke, Richard.
Morrow, James G.
Moyer, Albert.
Myers, J. E.

N

National Tube Company,
Frank N. Speller.
Nead, J. H.
Neal, C. S.
New Jersey Zinc Company,
Gilbert Rigg.
New York Central and Hudson River Railroad Company, Eng. Dept.,
A. W. Carpenter.
Norris, George L.

O

Olsen, Thorsten Y.
Onderdonk, J. R.
Ormsbee, J. Mason.
Orton, Edward, Jr.
Otis Elevator Company,
Myron Park Davis, 2d.
Owen, James.

P

Page, Logan Waller.
Page, W. Marshall.
Parmelee, Cullen W.
Pease, Burton H.
Peffer, George Whitesell.

Peirce, Edwin H.
Pennsylvania Steel Company, The,
Frank A. Robbins, Jr.
Perfection Spring Company,
Z. B. Leonard.
Petinot, N. G.
Pickard, Glenn H.
Pittsburgh Testing Laboratory,
Joshua L. Miner.
Polk, Anderson.
Pope, George S.
Potts, Stephen C.
Powers, W. A.
Pressed Steel Car Company,
H. J. Gearhart.
Price, William B.
Provost, Andrew J., Jr.

R

Ramage, J. C.
Randall, Theodore A.
Reading Iron Company,
George Schuhman.
Reinke, W. B.
Remington Arms and Ammunition Company,
Nathan A. Chase.
Reninger, Henry A.
Rich, Charles H.
Rigg, Ernest H.
Rigg, Gilbert.
Rights, Lewis D.
Rinald, C. D.
Ritter, Daniel E.
Robertson, H. H.
Robinson, A. F.
Rock Products,
Fred K. Irvine.
Roebling's Sons Company, John A.,
H. J. Horne.
Rogers, R. E.
Rome Merchant Iron Mill,
Weston Jenkins, Jr.
Royle and Sons, John,
Vernon E. Royle.
Rys, C. F. W.

S

Sabin, A. H.
Schaeffer, John A.
Scofield, H. H.
Seaman, Harry J.
Sharples, Philip P.
Shelley, Henry T.
Shore, Albert F.
Shuman, Jesse J.
Skinner, C. E.
Skinner, Hervey J.
Slater, W. A.
Slocum, Frank S.
Smith, E. B.
Smith, H. E.
Smither, F. W.
Snow, J. P.
Spackman Engineering Company, Henry S.,
Henry S. Spackman.
Spencer, Herbert.
Standard Steel Works Company,
A. A. Stevenson.
Stevenson, A. A.
Stone, George C.
Stoughton, Bradley.
Stratton, S. W.
Studebaker Corporation,
Fred M. Zeder.
Sturcke, H. E.
Swett, Bertram L.

T

Talbot, Arthur N.
Taylor, Knox.
Testing Laboratory, City of St. Louis,
Mont Schuyler.
Thomas, L. E.
Thompson, Gustave, W.
Thompson, Sanford E.
Tiemann, Hugh P.
Tilt, Edwin B.
Tinsley, John F.
Titanium-Alloy Manufacturing Company, The,
N. G. Petinot.

Trautwine, John C., Jr.
Tretch, William J.
Tyler Company, W. S.,
Guy A. Disbro.

U

Uhler, J. Lloyd.
Unger, J. S.
United Gas Improvement Company,
W. Herbert Fulweiler.

V

Van Gundy, C. P.
Veitch, F. P.
Voorhees, S. S.
Vredenburgh, Watson, Jr.

W

Wagner, Samuel Tobias.
Walker, Percy H.
Walker, William H.
Waring, F. M.
Warner, Charles.
Warwick, C. Laurence.
Webert, Louis P.
Webster, George S.
Webster, William R.
Wells, Walter F.,
G. L. Knight.
Western Electric Company,
Oscar Linder.
Westinghouse Air Brake Company,
Harry C. Loudenbeck.
Westinghouse, Church, Kerr and Company,
Cloyd M. Chapman.
Westinghouse Electric and Manufacturing Company,
T. D. Lynch.
Weymouth, Frederick A.
White, G. D.
Wickhorst, Max H.
Wig, Rudolph H.
Wight, Frank C.
(*Engineering News*).
Wilhelm Company, The A.,
Walter S. Davis.
Wille, H. V.
Wilson, Percy H.
Winchester Repeating Arms Company,
R. L. Penney.
Wood Iron and Steel Company, Alan,
Charles H. Rich.
Woodroffe, G. H.
Worth Brothers Company,
James L. Hughes.

Y

Yellow Pine Manufacturers' Association,
A. T. North.
Young, C. D.
Young, J. Bertram.
Youngstown Sheet and Tube Company,
E. T. McCleary.

Z

Zeleny, Frank.
Zimmerschied, K. W.

Total number, 343; attendance, not including companies, etc., whose representatives also hold membership in their own name, 318.

FIRST SESSION.—TUESDAY, JUNE 24, 11 A. M.

President Robert W. Hunt in the chair.

The minutes of the Fifteenth Annual Meeting were approved as printed.

The annual report of the Executive Committee was adopted as printed. That report contained the following proposal relating to the amendment of the by-laws:[1]

> "*Proposed Amendment of the By-Laws.*—It is recommended that Sec. 5, Art II, of the by-laws, which was inserted last year to serve a temporary need, be stricken out. The section in question reads as follows:
>
> "SEC. 5. The officers and members of the Executive Committee to hold office under these by-laws shall be as follows:
>
> "To hold office for one year:—the President elected this year (1912), the Second Vice-President, to be appointed by the Executive Committee, and the following members of the present Executive Committee: W. A. Bostwick, Robert W. Hunt, Richard Moldenke and William R. Webster.
>
> "To hold office for two years:—The First Vice-President elected this year (1912), the Secretary-Treasurer elected this year (1912), the three members of the Executive Committee elected this year (1912), and a fourth member to be appointed by the Executive Committee."

In the absence of Mr. J. A. Holmes, Chairman of Committee D-5 on Standard Specifications for Coal, the report of that committee was presented by Mr. George S. Pope, Secretary.

The Chair announced that at the request of Committee D-11 on Standard Specifications for Rubber Products, the presentation of the report of that committee would be deferred until a later session.

The report of Committee E-5 on Rules Governing the Form but not the Substance of Specifications, was presented by Mr. Edgar Marburg, Chairman.

Mr. R. J. Wig moved that all reports and recommendations of Committee E-5 affecting the form of specifications be submitted to letter ballot of the Society in the same manner as prescribed in Sec. 1, Art IV, of the by-laws, defining the procedure governing the adoption of standard specifications, and that the provisions of this motion be made retroactive and

[1] This amendment was adopted by letter ballot of the Society on August 25, 1913.—ED.

applicable to the existing regulations governing the form but not the substance of specifications. After some discussion this motion was put to vote and lost.

The report of Committee E-6 on Papers was presented by Mr. Edgar Marburg, Chairman.

Mr. R. J. Wig moved that the Executive Committee provide rules so that hereafter no reports of committees shall be received by the Society unless a statement is appended showing that all members of the committee have had an opportunity of considering such reports and showing their approval or disapproval; this statement to be published with the report.

After some discussion Mr. G. W. Thompson moved as an amendment to this motion that the matter be referred to the Executive Committee without limitation. This amendment was seconded and the motion as thus amended was adopted.

The Chair announced that the tellers, Mr. J. H. Gibboney and Mr. S. V. Hunnings, who had been appointed by the Chair to canvass the vote on the election of officers and members of the Executive Committee, had reported that 320 legal ballots had been cast; and in accordance with their report the Chair declared the election of Mr. Arthur N. Talbot, President; Mr. Richard Moldenke, Vice-President; Mr. W. H. Bixby, Mr. John Brunner, Mr. F. H. Clark and Mr. Albert Sauveur, members of the Executive Committee.

Mr. R. J. Wig introduced the following motion on behalf of 32 members of the Society:

> "It is moved that the following proposed amendment to Sec. 9, Art II, of the by-laws of the Society be referred to the Executive Committee for their consideration, and that it be subsequently referred to the Society prior to February 1, 1914, with such suggested amendments as will result in a democratic method of administration of the affairs of the Society, to be voted upon at the next annual meeting.
>
> "Strike out:
>
> "SEC. 9. The election of officers and members of the Executive Committee shall be by letter ballot. The Executive Committee, before each annual meeting, shall appoint a Nominating Committee, whose duty it shall be to nominate a full list of officers. The list of nomina-

tions so made shall be submitted to the membership not more than eight (8) nor less than four (4) weeks before the coming annual meeting.

"Substitute:

"The Secretary shall send at least twelve weeks before the annual meeting, to all active members of the Society, a blank nominating ballot indicating the officers to be elected and the vacancies to be filled. Each member is to nominate one candidate for each office or vacancy to be filled. These nominating ballots must be returned and received by the Secretary not later than nine weeks prior to the annual meeting. The President shall appoint a canvassing committee of three members to count the ballots and certify to the Secretary the names of the candidates receiving the two highest number of votes received by each. The Secretary shall send to all active members, six weeks prior to the annual meeting, election ballots containing the names of the candidates certified by the canvassing committee together with the number of votes received by each. The members of the Society shall vote only for the candidates on the official ballot. The poll shall be closed and the ballots counted at the business session of the annual meeting. Those receiving the highest number of votes shall be declared elected. In case of a tie vote, the deciding vote shall be cast by the presiding officer."

Mr. Robert W. Lesley moved as an amendment to this motion that the words

> "and that it be subsequently referred to the Society prior to February 1, 1914, with such suggested amendments as will result in a democratic method of administration of the affairs of the Society, to be voted upon at the next annual meeting.",

be stricken out. This motion was seconded.

Mr. Wig declined to accept the amendment.

Mr. D. E. Douty raised the point of order that a motion to amend the by-laws is not subject to amendment, in which he was not sustained by the Chair.

The Chair then ruled the original motion out of order, as failing to comply with the provisions governing amendments in Sec. 1, Art. VI, of the by-laws.

The Secretary moved:

> "That the Executive Committee be requested to draw up, if in its judgment it is desirable to do so, proposed

amendments to the by-laws by which the scheme of nomination of officers would be made such that the membership at large may participate individually, directly or indirectly, in these nominations, and that the report of the Executive Committee in this matter be made not later than February 1, 1914."

This motion was carried.
The meeting then adjourned till 3 p. m.

SECOND SESSION.—TUESDAY, JUNE 24, 3 P. M.

On Preservative Coatings.

President Robert W. Hunt in the chair.

The report of Committee D-1 on Preservative Coatings for Structural Materials was presented by Mr. P. H. Walker, Chairman. On motion of Mr. Walker the proposed Standard Specifications for the Purity of Raw Linseed Oil from North American Seed were referred to letter ballot of the Society with the following amendments:

1. Introduce the word "or" between the two references to specific gravity in Section 1. Change the maximum limit for the saponification number from the original figure, "192," to "195."

2. Change the paragraph on "Specific Gravity," Section 2, from the original form, namely:

"Use a pyknometer, accurately standardized and having a capacity of at least 25 cc., making a test of 15°.5 C., water being 1 at 15°.5 C. and another test at 25° C., water being 1 at 25° C."

to the following form:

"Use a pyknometer, accurately standardized and having a capacity of at least 25 cc., or any other equally accurate method, making a test at 15° C., water being 1 at 15°.5 C., or a test at 25° C., water being 1 at 25° C"

3. Change the paragraph on "Refractive Index", Section 2, from the original form, namely:

"Using Abbé Refractometer at 25° C."

to the following form:

"Use a properly standardized Abbé Refractometer at 25° C., or any other equally accurate instrument."

The proposed Standard Definitions of Terms used in Paint Specifications were on motion of Mr. Walker referred to letter ballot of the Society.[1]

In connection with the discussion of this report Mr. C. D. Rinald offered the following motion:

"That all members of the American Society for Testing Materials, either firms or individuals, who by their contribution of material shall make possible the conduct of tests that may have been decided upon by a committee or sub-committee, shall thereby become non-voting members of such committees. They shall be notified in advance of all meetings and inspection of such committees at which they may have their representatives, and they shall also receive all information furnished to members of such committees. Nobody connected either directly or indirectly with contributing firms or individuals shall be allowed to vote on competing articles."

The Chair in putting this motion stated that he would do so with the understanding that according to the usual procedure the motion would be referred with power to the Executive Committee. The motion was carried.

Mr. G. W. Thompson, Secretary of Committee D-1, read a letter from Messrs. Smith, Emery & Co., members of the Society, in criticism of the proposed Standard Specifications for the Purity of Raw Linseed Oil from North American Seed. The Secretary moved that this communciation be referred to Committee D-1 with the request that it be given due considera-

[1] Since some of these definitions do not comply with the requirements in the Regulations Governing Technical Committees, that proposed standard definitions shall be printed in the Proceedings for at least one year before being referred to the Society for adoption, these definitions have not been sent out to letter ballot.—ED.

tion at the next meeting of that committee. The motion was carried.

The report of Committee D-2 on Standard Tests for Lubricants was presented, in the absence of Mr. A. H. Gill, Chairman, by Mr. I. C. Allen, a member of the committee. Mr. Allen stated on behalf of himself and Mr. J. M. Jeffers, Secretary of the committee, that there was considerable opposition both as to the substance and the wording of the report of the committee, and moved that it be referred back to the committee for further consideration.

The Chair ruled that under the circumstances stated by Mr. Allen the report would be referred back to the committee without calling for a vote on Mr. Allen's motion.

The following papers were then presented and discussed:

"Tests on the Rate of Corrosion of Metals," by Mr. A. W. Carpenter.

"Testing of Chinese Wood Oil," by Mr. E. W. Boughton.

"Outline of a Test for Indicating the Relative Priming and Top-Coat Values of Different Paints," by Mr. M. McNaughton.

The meeting then adjourned till 8 p. m.

THIRD SESSION.—TUESDAY, JUNE 24, 8 P. M.

On Steel.

Vice-President A. W. Gibbs in the chair.

The Annual Presidential Address entitled "Application of Specifications" was presented by the retiring President, Mr. Robert W. Hunt.

The report of Committee A-4 on Heat Treatment of Iron and Steel was presented, in the absence of Mr. Albert Sauveur, Chairman, by Mr. John H. Hall, Secretary of the committee.

The following three papers relating to the heat treatment of steel were then presented and discussed jointly:

"Effect of Size of Section on Physical Properties Developed by Heat Treatment," by Mr. J. H. Nead.

"Influence of Mass in the Heat Treatment of Steel," by Mr. K. W. Zimmerschied.

"Heat Treatment of Hypo-Eutectoid Carbon-Steel Castings," by Mr. J. H. Hall.

The meeting then adjourned till the following morning.

FOURTH SESSION.--WEDNESDAY, JUNE 25, 10 A. M.

On Steel.

President Robert W. Hunt in the chair.

Mr. W. K. Hatt presented a "Condensed Report of the Investigation of Reinforcing Bars Rerolled from Steel Rails," conducted under instructions from Sub-Committee V of Committee A-1 on Standard Specifications for Steel.

On motion of Mr. A. A. Stevenson the value of Mr. Hatt's investigation and report was recognized by a vote of thanks.

The report of Committee A-1 on Standard Specifications for Steel was presented, on invitation of Mr. W. R. Webster, Chairman, by Mr. A. A. Stevenson, Vice-Chairman of the Committee.

The action on this report may be summarized as follows:

The following changes in addition to those recommended in the report were authorized in the proposed revised Specifications for Lap-Welded and Seamless Steel Boiler Tubes, with a view of harmonizing these specifications with those of the American Railway Master Mechanics' Association:

1. Strike out the following Section 4 (*a*):

"A test specimen not less than 4 in. in length shall have a flange $\frac{3}{8}$ in. wide turned over at right angles to the body of the tube without showing cracks or flaws."

Substitute the following:

"A test specimen not less than 4 in. in length shall have a flange turned over at right angles to the body of the tube without showing cracks or flaws. This flange, as measured from the outside of the tube, shall be $\frac{3}{8}$ in. wide for tubes $2\frac{1}{2}$ in. or under in outside diameter, and $\frac{1}{2}$ in. wide for tubes over $2\frac{1}{2}$ in. in outside diameter."

2. Strike out the following Section 7:

"Tubes under 0.125 in. in thickness shall stand an internal hydraulic pressure of 900 lb. per sq. in.; tubes 0.125 in. or over in thickness shall stand an internal hydraulic pressure of 1000 lb. per sq. in."

Substitute the following:

"Tubes under 5 in. in diameter shall stand an internal hydraulic pressure of 1000 lb. per sq. in.; and tubes 5 in. or over in diameter shall stand an internal hydraulic pressure of 800 lb. per sq. in."

3. Strike out the table in Section 11, and substitute the following table:

Thickness.		Weight, lb. per ft. of length. Outside Diameter, in.												
In.	Nearest B. w. g.	1¾	2	2¼	2½	3	3½	4	4½	5	5¼	5⅜	5½	6
0.095	13	1.68	1.93	2.19	2.44	....	....	....	....	....	....	....	....	....
0.110	12	1.93	2.22	2.51	2.81	3.40	....	....	....	....	....	....	....	....
0.125	11	2.17	2.50	2.84	3.17	3.84	4.51	....	....	....	....	....	....	....
0.135	10	2.33	2.69	3.05	3.41	4.13	4.85	5.57	....	....	....	....	....	....
0.150	9	2.56	2.96	3.36	3.76	4.57	5.37	6.17	6.97	7.77	8.17	8.37	8.57	9.37
0.165	8	....	....	....	4.11	5.00	5.88	6.76	7.64	8.52	8.96	9.18	9.40	10.28
0.180	7	....	....	....	4.46	5.42	6.38	7.34	8.30	9.27	9.75	9.99	10.23	11.19

4. Strike out the following Section 15:

"The name or brand of the manufacturer, and 'Tested at 900 lb.' for tubes under 0.125 in. in thickness, and 'Tested at 1000 lb.' for tubes 0.125 in. or over in thickness, shall be legibly stenciled in white on each tube."

Substitute the following:

"The name or brand of the manufacturer, and 'Tested at 1000 lb.' for tubes under 5 in. in diameter, and 'Tested at 800 lb.' for tubes 5 in. or over in diameter, shall be legibly stenciled in white on each tube."

The following matter was referred to letter ballot of the Society:

PROPOSED REVISIONS IN STANDARD SPECIFICATIONS.

For Steel Splice Bars.
For Structural Steel for Bridges.
For Structural Nickel Steel.
For Structural Steel for Buildings.
For Steel Reinforcing Bars.
For Steel Axles.
For Steel Tires.

For Steel Castings.
For Lap-Welded and Seamless Steel Boiler Tubes (amended as above stated).
For Automobile Carbon and Alloy Steels.
For Boiler and Firebox Steel.
For Boiler Rivet Steel.
For Annealed Steel Forgings.
For Steel Shapes, Universal Mill Plates, and Bars.

PROPOSED NEW STANDARD SPECIFICATIONS.

For Medium-Carbon Steel Splice Bars.
For High-Carbon Steel Splice Bars.
For Extra-High-Carbon Steel Splice Bars.
For Structural Steel for Ships.
For Rivet Steel for Ships.
For Rail-Steel Concrete Reinforcement Bars.
For Cold-Rolled Steel Axles.
For Wrought Solid Carbon-Steel Wheels for Electric Railway Service.
For Blooms, Billets and Slabs for Carbon-Steel Forgings.

Committee A-1 was instructed to consider the following matters and to report their conclusions at the next annual meeting:

1. The reduction of the specified limit of the ultimate strength of rivet steel from 48–58,000 to 46–54,000 lb. per sq. in.
2. The relation between the yield point and the ultimate strength in all of the standard specifications for steel.
3. The permissible camber in both planes, and its direction in a horizontal plane, for medium-carbon, high-carbon, and extra-high-carbon splice bars.
4. The allowance of ten per cent excess on check analysis for sulphur for castings for railway rolling stock.

A vote of thanks was adopted expressive of the appreciation of the meeting of the results of the labors of Committee A-1.

Owing to the lateness of the hour, the presentation of the following papers, scheduled for this session, was postponed:

"Rail Failures and Their Causes," by Mr. M. H. Wickhorst.

"Resistance of Steels to Wear in Relation to Their Hardness and Tensile Properties," by Mr. George L. Norris.

The meeting then adjourned till 8 p. m.

FIFTH SESSION.—WEDNESDAY, JUNE 25, 8 P. M.

On Steel and Wrought Iron.

President Robert W. Hunt in the chair.

The following papers whose presentation had been deferred from the morning session, were read by their authors and discussed:

"Rail Failures and Their Causes," by Mr. M. H. Wickhorst.

"Resistance of Steels to Wear in Relation to Their Hardness and Tensile Properties," by Mr. George L. Norris.

The Secretary stated that he had been instructed by unanimous vote of the Executive Committee to introduce the following resolution, with the understanding that in case of affirmative action the resolution would be referred to letter ballot of the Society:

> "*Resolved*, That from and after September 1, 1913, the Regulations Governing Technical Committees shall be made applicable to all existing technical committees of the Society, irrespective of the circumstance that the organization of certain committees antedated these regulations."

On motion, this resolution was adopted, subject to the above-stated provision.[1]

The report of Committee A-2 on Standard Specifications for Wrought Iron was presented by Mr. S. V. Hunnings, Chairman. On recommendation of the committee, the following matters were referred to letter ballot of the Society:

1. Proposed revisions in the following Standard Specifications:

For Engine Bolt Iron;

For Refined Wrought Iron Bars.

2. The adoption of proposed Standard Specifications for Wrought-Iron Plates.

[1] This resolution was adopted by letter ballot of the Society on August 25, 1913.—ED.

The report of Committee A-8 on Standard Specifications for Cold-Drawn Steel was presented by Mr. C. E. Skinner, Chairman.

Following the discussion of this report, a paper entitled "Results of Tests of Welded Boiler Tubes," by Mr. E. L. Lasier, was read by title in the absence of the author.

The following papers were then presented by their respective authors and discussed:

"Mechanical Tests of Heat-Treated Spring Steel," by Mr. R. P. Devries.

"Oxygen in Iron and Steel: Value of Existing Methods for Its Determination," by Mr. W. R. Fleming.

"Magnetic Criterion of the Mechanical Properties of a One-per-cent-carbon Steel," by Mr. Charles W. Burrows.

A paper on "Notes on the Property of Toughness in Metals," by Mr. Albert F. Shore, was read by title.

The report of Committee D-11 on Standard Specifications for Rubber Products, which had been deferred from the first session, was presented by Mr. E. B. Tilt, Chairman.

The meeting then adjourned till the following morning.

SIXTH SESSION.—THURSDAY, JUNE 26, 10 A. M.

On Cement and Concrete.

Vice-President A. N. Talbot in the chair.

The following committee reports were read by title:

Committee C-1 on Standard Specifications for Cement, Mr. George F. Swain, Chairman.

Committee C-2 on Reinforced Concrete, Mr. F. E. Turneaure, Chairman.

The following papers were then presented by their respective authors and discussed:

"Estimation of Fine Particles in Cement by Rate of Hydration," by Mr. H. S. Spackman.

"Action of Various Substances on Cement Mortars," by Mr. Richard K. Meade.

"Method and Apparatus for Determining Consistency," by Mr. Cloyd M. Chapman.

"Results Obtained with the Autoclave Tests for Cement," by Mr. H. J. Force.

On motion of Mr. Robert W. Lesley, and with the approval of the author, Mr. Force's paper on "Results Obtained with the Autoclave Tests for Cement" was accepted, with the understanding that it would be printed in the Proceedings, and that it would be referred to Committee C-1 on Standard Specifications for Cement.

In view of the lateness of the hour, the presentation of a paper on "Screen-Scale Sieves made to a Fixed Ratio," by Mr. G. A. Disbro, was deferred.

The meeting then adjourned till 3 p. m.

SEVENTH SESSION.—THURSDAY, JUNE 26, 3 P. M.

On Cement, Concrete and Waterproofing.

Vice-President A. N. Talbot in the chair.

The report of Committee D-8 on Waterproofing Materials was presented by Mr. W. A. Aiken, Chairman. After some discussion this report, on motion of Mr. R. J. Wig, was referred back to the committee for further consideration.

A paper on "Coal-Tar and Asphalt Products for Waterproofing," by Mr. S. T. Wagner, was presented and discussed.

The following three papers were then presented and discussed jointly:

"Test of Natural Concrete Aggregates," by Mr. Russell S. Greenman.

"Tests of Mortars Made from Wisconsin Aggregates," by Mr. M. O. Withey (presented by title).

"Observations on the Testing of Sand," by Mr. W. B. Reinke.

A paper on "Tests of Reinforced Concrete Slabs under Concentrated Loading" was presented by Mr. A. T. Goldbeck and discussed.

A paper on "Test of a 40-foot Reinforced Concrete Highway Bridge," by Mr. D. A. Abrams, was read by title in the absence of the author.

A paper on "Thermal Activities of Portland Cement during the Period of Setting," by Mr. Louis N. Beals, Jr., was presented, in the absence of the author, by Mr. Mont Schuyler, and discussed.

A paper on "Screen-Scale Sieves Made to a Fixed Ratio," the presentation of which had been postponed from the previous session, was presented by its author, Mr. G. A. Disbro.

The meeting then adjourned till the following morning.

EIGHTH SESSION.—FRIDAY, JUNE 27, 10 A. M.

On Ceramics and Road Materials.

President Robert W. Hunt in the chair.

The report of Committee C-3 on Standard Specifications for Brick was presented by Mr. A. V. Bleininger, Chairman.

On motion of Mr. R. J. Wig, the action taken at the previous session, by which the report of Committee D-8 on Waterproofing Materials was referred back to that committee, was reconsidered; and it was decided that if that committee should, by unanimous vote, adopt certain proposed modifications in their report, the report was to be printed in the Proceedings.[1]

The report of Committee C-4 on Standard Specifications and Tests for Clay and Cement Sewer Pipes was presented, in the absence of the Chairman, Mr. Rudolph Hering, by the Secretary, Mr. A. J. Provost, Jr.

The report of Committee C-6 on Standard Tests and Specifications for Drain Tile was presented by Mr. A. Marston, Chairman. On motion of Mr. L. G. Blackmer, it was decided to refer to the committee, with power, the omission of the words distinguished by italics in the following sentence at the middle of the fifth page of the report:[2]

> "This method alone does not provide safety against the cracking of pipes in ditches *now so prevalent in all the large sizes of both drain tile and sewer pipe, for pipe of the*

[1] The proposed modifications given on p. 465 having been adopted by unanimous vote of Committee D-8, the revised report appears on pp. 459–465.—ED.

[2] For action taken by Committee C-6 on this recommendation, see p. 311. The report in revised form appears on pp. 303-311.—ED.

best quality now made will generally crack in deep and wide ditches, though sound and satisfactory in every way for ordinary moderate depths and widths."

The report of Committee C-7 on Standard Specifications for Lime was presented by Mr. H. S. Spackman, Chairman. On motion of Mr. F. P. Veitch, it was decided that this report should be printed in the Proceedings, but that it shall be referred back to the committee for further consideration.

The report of Committee D-4 on Standard Tests for Road Materials was presented by the Chairman, Mr. L. W. Page, together with a minority report by two members of the committee. The discussion of this report was introduced by Mr. Page by the presentation of a reply to the minority report on behalf of the Sub-Committee on Nomenclature of Committee D-4.

A paper on "Testing of Refractories" was presented by Mr. A. V. Bleininger and discussed.

On motion of Mr. E. Orton, Jr., the Executive Committee was requested to consider the desirability of appointing a Committee on Refractories.

A paper on "Relation between the Tests for the Wearing Qualities of Road-Building Rocks" was presented by Mr. L. W. Page and discussed.

A paper on "Extractor for Bituminous Paving Mixtures," by Mr. C. N. Forrest, was read by title.

The meeting then adjourned till 3 p. m.

NINTH SESSION.—FRIDAY, JUNE 27, 3 P. M.

On Non-Ferrous Metals.

Vice-President A. W. Gibbs in the chair.

The report of Committee B-1 on Standard Specifications for Copper Wire was presented by Mr. J. A. Capp, Chairman.

The proposed revisions in the following standard specifications recommended by Committee B-1 were referred to letter ballot of the Society:

For Hard-Drawn Copper Wire.
For Medium Hard-Drawn Copper Wire.
For Soft or Annealed Copper Wire.

The report of Committee B-2 on Non-Ferrous Metals and Alloys was presented by Mr. William Campbell, Chairman.

On recommendation of the committee, the following proposed standard specifications, which are designed jointly to supersede the present Standard Specifications for Copper Wire Bars, Cakes, Slabs, Billets, Ingots, and Ingot Bars, were referred to letter ballot of the Society:

For Lake Copper Wire Bars, Cakes, Slabs, Billets, Ingots, and Ingot Bars.

For Electrolytic Copper Wire Bars, Cakes, Slabs, Billets, Ingots, and Ingot Bars.

The following papers were presented by their authors and discussed:

"Lead-Tin-Antimony and Tin-Antimony-Copper Alloys," by Mr. William Campbell.

"Study of Bearing Metals and Methods of Testing," by Mr. T. D. Lynch.

A paper on "Strength of Cast Zinc or Spelter," by Mr. Gilbert Rigg and Mr. G. M. Williams, was presented by Mr. Rigg and discussed.

The meeting then adjourned till the following morning.

TENTH SESSION.—SATURDAY, JUNE 28, 10 A. M.

On Testing and Miscellaneous Subjects.

President Robert W. Hunt in the chair.

The report of Committee E-1 on Standard Methods of Testing was presented by Mr. Gaetano Lanza, Chairman.

The report of Committee A-10 on Hardness Tests was presented by the Chairman, Mr. D. E. Douty.

A paper on "Conservation and Shipping Containers" was presented by Col. B. W. Dunn, who then introduced the following resolution:

"*Resolved*, That the American Society for Testing Materials, on account of its desire to cooperate and assist in any action that promises to conserve our national resources, respectfully urges upon the Interstate Commerce

Commission the advisability of extending, to all classes of freight moving in interstate commerce, the protection against damage and loss through insecure shipping containers that the Commission is now endeavoring to extend to explosives and other dangerous articles; and this Society offers the services of a committee, whose appointment for this purpose is hereby authorized, to assist, so far as the time and experience of its members may permit, in formulating and perfecting standard specifications for shipping containers."

On motion of the Secretary, the first part of this resolution, ending with the words "and other dangerous articles," was adopted as expressive of the sense of the meeting; and the remainder of the resolution was referred with power to the Executive Committee, with a favorable recommendation.

A paper on "Suggestions as to Standard Specifications to Promote Efficiency and Safety in Explosives Used in Blasting," by Mr. C. P. Beistle, was presented, in the absence of the author, by Col. B. W. Dunn.

A paper on "Spherical Bearings," by Mr. Mont Schuyler, was read by title in the absence of the author.

A paper on "Use of the Strain Gage in the Testing of Materials," by Mr. W. A. Slater and Mr. H. F. Moore, was presented by Mr. Slater and discussed.

A paper on "Large-Capacity Testing Machines in United States and England," by Mr. E. L. Lasier, was read by title in the absence of the author.

On motion of the Secretary, a resolution was passed, by unanimous vote, expressive of the thanks of the meeting to the Bausch & Lomb Optical Co., and to their representative, Mr. H. E. Howe, for the service rendered the Society by the excellent provision for the illustration of papers.

The following resolution, introduced by Mr. D. E. Douty, was then adopted:

"*Whereas*, The new method of presenting papers by preparation and distribution of preprints in advance and during the meetings has developed a distinct improvement in the interest and value of the sessions; be it

"*Resolved*, That the Society heartily endorse the new

method, the additional expense incurred thereby, and the extension of the system; and be it further

"*Resolved*, That the sincere thanks of the Society be extended to our Secretary and his associates for the very convenient and efficient manner in which these preprints have been furnished to the members."

On motion of Mr. E. J. Mehren, a resolution was passed expressive of the thanks of the meeting to President Hunt, for the able, courteous and considerate manner in which he had conducted the meeting. This motion was put by President-elect A. N. Talbot, and unanimously adopted by a rising vote.

The Chair then declared the meeting adjourned *sine die*.

American Society for Testing Materials.

AFFILIATED WITH THE

International Association for Testing Materials.

PROCEEDINGS.

The Society is not responsible, as a body, for the statements and opinions advanced in its publications.

THE APPLICATION OF SPECIFICATIONS.

Annual Address by the President, Robert W. Hunt.

The past year was made a notable one in the history of our Society by our having acted as hosts to the International Association for Testing Materials on the occasion of that organization's Sixth Congress. Having that Congress held in this country was an ardent desire of our late honored and loved President, Doctor Dudley. I am sure that many of you will recall how earnestly he advocated such an invitation being extended by this Society, and how gratified he was by its action empowering him as its President to deliver such a message to the Association's Council when he attended the Copenhagen Congress, and with how much evident pleasure he announced to us that the invitation had been accepted; apparently, through his always great modesty, not at all realizing the important part which his charming personality had played in influencing the acceptance.

Doctor Dudley's mind was full of plans for making the American Congress a success, and it was a great pity that he was not spared to participate in the event, toward the happening of which he had done so much. We, who were here, tried to be worthy of the trust left to us, and, thanks to the generous support of many of our Society's friends, and the self-sacrificing

work of your several committees, to whom the work was intrusted, I am certain that the Congress and all pertaining to it passed off in a manner which would have been to Doctor Dudley's satisfaction, and which was gratifying to our visitors, as they have both personally and officially assured us.

On behalf of the American Society for Testing Materials, I take this occasion to most heartily thank the various industrial organizations and individuals who so generously contributed money for the occasion, and also those who added so much to the pleasure and profit of our foreign visitors by giving them the privilege of visiting their various establishments, and, in many instances, also extending to them gracious hospitality. We had the satisfaction of returning to our money contributors a very respectable percentage of their donations. To the others we can only give appreciative thanks.

I also desire to officially thank the members of the various committees who had the detail work of the entertainment of our visitors and the operations of the Congress, for their labors, and to congratulate them upon the great successes accomplished. I am certain that in every way the holding of the Congress in this country was of value and did much to benefit our Society. The bringing together of so many men of high scientific attainments and practical experience in widely separated fields, and not only enabling them to exchange professional ideas, but also to become personally acquainted, was certain to result in good, and their presence in this country attracted the attention of its men of affairs and did much to impress them with a greater appreciation of the value of our own Society on not only what may be called the technical side of the matters with which it is identified, but also the absolutely practical—the money value —of our deliberations and conclusions.

In the not distant past there was a more or less general feeling among the manufacturers of this country that specifications covering their products were entirely unnecessary. If it amused a customer to formulate such things and present them as describing that which they desired to purchase, well and good, but that the products should actually conform to the details of what they considered purely academic requirements, was a different proposition. They had been for years engaged in their

several occupations and naturally knew more about them than was possible for any outsider. In a way, this was true, but the element of progression was involved, with the result that what had been equal to, and, therefore, satisfactory, under the requirements of yesterday, became inadequate to the demands of to-day; and the situation could be best met by accurate observations of the behavior of materials of known composition under carefully observed conditions and measured stresses, and it is patent that without complete knowledge of observed materials, the obtained results would be so obscured that accurate deductions would be impossible. In many cases, the conditions under which materials are to be used are so widely different, that what would be satisfactory in one case, would be very unsatisfactory in another.

With the progress of affairs, and, in fact, as part of such progress, has come the organization of technical societies. They have played and are filling an important part in the world's scientific and material advancement. The societies dealing with production and application of materials and power have brought together the brightest minds and most enterprising of the world's workers, who have, quicker and more thoroughly than would have been in any other way possible, found that no matter how smart each man might be and how much he might know, it would not be all, and that, through comparing notes and so exchanging knowledge with his fellows, he was certain to ultimately receive at least as much as he gave. That such is true is now accepted, and the day of closed shops and self-sufficiency forever passed. With this has also come the day of specifications, but, as yet, let them be drawn ever so carefully, and based on the most careful observation, they cannot entirely take the place of and make unnecessary the exercise of initiative on the part of the producer. Specifications have to be not only adapted to the conditions under which the materials are to be used, but they also have to be intelligently applied to the production of the materials they are intended to cover. They must be kept practical. There is no question that steel absolutely without any phosphorus in its composition would be most desirable, but, so long as such metal is practically unattainable, why specify it? And knowing that the

available iron ores of a country are best adapted to certain processes, it would seem unwise to expect their engineers to adopt specifications which would leave their own people out of of the running.

It is thought by many that one of the most desirable results of the International Association for Testing Materials and its Congresses, will be the adoption of International Specifications. It is only in a somewhat restricted degree that I concur in that view. I think that for many years to come most countries will demand specifications which will best apply to their own circumstances either of production or use, or both. While, for instance, Germany is a large and successful producer of basic Bessemer steel, it has been proven by two costly failures that the ores of the United States are not adapted to the economical production of such steel; therefore, this country cannot be expected to have much interest in international basic Bessemer steel specifications. Still, adhering to my own shop, it is patent that so long as European railways have their present light equipment and short lines, they will not require the same character of rails as our American roads; nor do they need the same details for their equipment. There are many other instances in which different countries will, for their own use, require different specifications, no matter where the products may be made, but there is one international field on which all countries can unite, and that is in the studying and discussion of scientific investigations and the details of the testing of materials, and, on the results thus obtained and mutually discussed, valuable specifications can be based. To be of value, they cannot be purely academic, and bringing into personal contact the scientist and the intelligent practitioner is certain to result in real progress.

As already stated, no matter how carefully specifications may be formulated, they cannot eliminate the necessity for judgment being exercised in their application. Unusual conditions may, and frequently do, arise, and of such character that it would have been practically impossible to have provided for them in the specifications. Probably as much attention has been given in this country to specifications for steel rails as for any other product. Three of the national technical societies

have had able committees upon the subject, and it has received at their hands years of careful investigation and consideration. The present Rail Committee of the American Railway Engineering Association is composed of some of the ablest railway engineers of this country, and they have had placed at their command facilities for observation and money for experiment, and the steel rail specifications approved by them are generally accepted by the American railway world as being *ex cathedra;* but that they, if blindly followed, will not insure satisfactory products has lately been most strikingly illustrated. Their specifications provide that if, under certain conditions, the drop test piece which is to be taken from the top end of the top rail of the ingot fails, all of the top rails from that heat shall be rejected, and a second test shall then be made of a test piece cut from the top end of any second rail of the same heat; and if that piece fails, all the second rails of the heat shall be also rejected, and a third test made from a top piece taken from any third rail of the heat; and if it also fails, all the remainder of the rails made from that heat shall be rejected.

It occurred lately that on an order for rails under the above named specifications, a large percentage of the top rails failed, about 22 per cent, and about 20 per cent of the test pieces from the second rails of those same heats also failed, and about 40 per cent of the third rails tested from that 20 per cent also failed, and, therefore, the entire heats represented by these last rails were condemned. The chemistry of all of the steel was clearly within the specifications, and, under a strict interpretation of them, only the top rails of the failed heats plus the second rails of heats whose second rails also failed, plus the entire heats represented by the failed third rails, would have been rejected; but with steel giving such a heavy percentage of unsatisfactory results, and realizing that, at best, the tested pieces were but a small proportion of all the metal represented, it was decided not to ship any of the rails which had been rolled on the order; which, in my judgment, was a wise non-adherence to the letter of the specifications. But such instances do not at all prove that specifications are without value. They afford an available means of formulating the most advanced state of the art, and, if drawn according to the best judgment of men familiar with

the practical workings of that art, they will be to the highest interest of both producer and user.

As evidenced by the reports of our Society's several committees, they have been active since our last meeting upon the various subjects coming under their several jurisdictions, and their reports and recommended specifications which are before the Society for consideration, give positive proof of the vast amount of labor and careful thought which have been given them. It is especially true of our organization that our committees are the vital element in its life, and I take great pleasure and pride in the feeling that at no time in the Society's history has its whole membership been more keenly interested in its work.

It was my fortune to follow in office most distinguished and able men, and it is a great satisfaction to know that I am to welcome as my successor a gentleman who has accomplished so much in engineering investigation, and whose fame as an authority on his chosen lines is world wide. And I congratulate you, my fellow members, that our Society enters upon another year in such a prosperous condition, and with so bright an outlook for the future.

ANNUAL REPORT OF THE EXECUTIVE COMMITTEE.

International Congress.—The most notable event in the activities of the Society during the past year was the Sixth Congress of the International Association for Testing Materials, held under its auspices in New York City on September 2–7, 1912. Although that Congress may deservedly be regarded as successful from every point of view, it was especially so in the extent, variety and value of the technical matter it brought together from contributors in many countries. It should be especially gratifying to the members of the American Society that of the 153 contributions presented at the Congress no fewer than 38 came from American sources. The Proceedings of this Congress, which will be published in German, French and English, are expected to be available in the near future in the form of two volumes of about 1100 pages each. The acceptance for publication of this large volume of technical matter, which is about twice as great as at any previous Congress, was rendered possible only through a subvention of $9000 on the part of the American Organizing Committee and a subscription of $5000 on the part of the American Society. The latter was conditioned on an agreement by which every Member of the American Society irrespective of membership in the International Association, will receive in due course a copy of the Congress Proceedings which will be bound by the American Society in conformity with the standard binding of its own Proceedings.

The Executive Committee desires again to express its grateful appreciation of the efficient and unselfish services rendered by many members without whose zealous cooperation with the Organizing Committee the success of the Congress would not have been possible.

It is fitting that the following communication from the officers of the International Association, which has already been brought to the notice of the members of the American Society, should here be placed permanently on record:

ST. PETERSBURG, December 5, 1912.

THE AMERICAN SOCIETY FOR TESTING MATERIALS,
Philadelphia, Pa.

Dear Sirs:

We have great pleasure in thanking you most warmly, in the name of the International Association for Testing Materials, for your extreme courtesy afforded to our Congress, your great assistance in preparing for it, for your furtherance of our aims in every possible manner, and in particular for the cordial reception given to our members.

Our members returned home full of satisfaction and carried away with them a vivid recollection of the marvelous technical achievements of your country, and of its natural beauties, and they are full of gratitude for your lavish hospitality.

We are firmly convinced that this Congress will succeed in gaining new adherents to our common aims, in developing the testing of materials as one of the chief safeguards for the general public, and that the bond of personal interest thus formed between the members of your Society and our Association will be productive of beneficial results.

With the renewed expression of our most sincere thanks, and our highest esteem,

In the name of the Council of the International Association for Testing Materials,

Yours very truly,

The General Secretary:
(Signed) ERNST REITLER.

The President:
(Signed) N. BELELUBSKY.

It is appropriate, too, that the Executive Committee should here record again its grateful acknowledgment of the generous financial support of the Congress at the hands of 443 members of the Society and other subscribers who jointly contributed $38,583.93, which, together with the receipts from Congress fees, rendered available the total sum of $42,364.60 for Congress purposes. The expenditures, including the refunding of one-sixth of the subscriptions, have previously been accounted for and will therefore not be recapitulated here. The final report of the auditors of the Congress accounts to the Executive Committee of the American Society, is as follows:

In conformity with the instructions of Mr. Edgar Marburg, we hereby certify that we have made an audit and examination of the cash account of the Treasurer of the Organizing Committee, Mr. Edgar Marburg, at his office in Philadelphia.

We further certify that we have found the accounts to be correct and to be as stated in the annexed report. All disbursements claimed by him were

substantiated by properly approved vouchers, and the balance as stated on hand was found to be correct as per settled bank book."

(Signed) JOHN HEINS & Co.,
Public Accountants and Auditors.

Membership.—It will be recalled that the last annual meeting of the Society was held in March instead of June with a view of not trenching on the International Congress in September. The following records are to be understood therefore as covering a period of about fifteen months instead of the usual annual period.

The membership at the last annual meeting was 1430. Since then 294 applications for membership have been approved. Happily the deaths for the period in question have been remarkably few. The losses by death are:

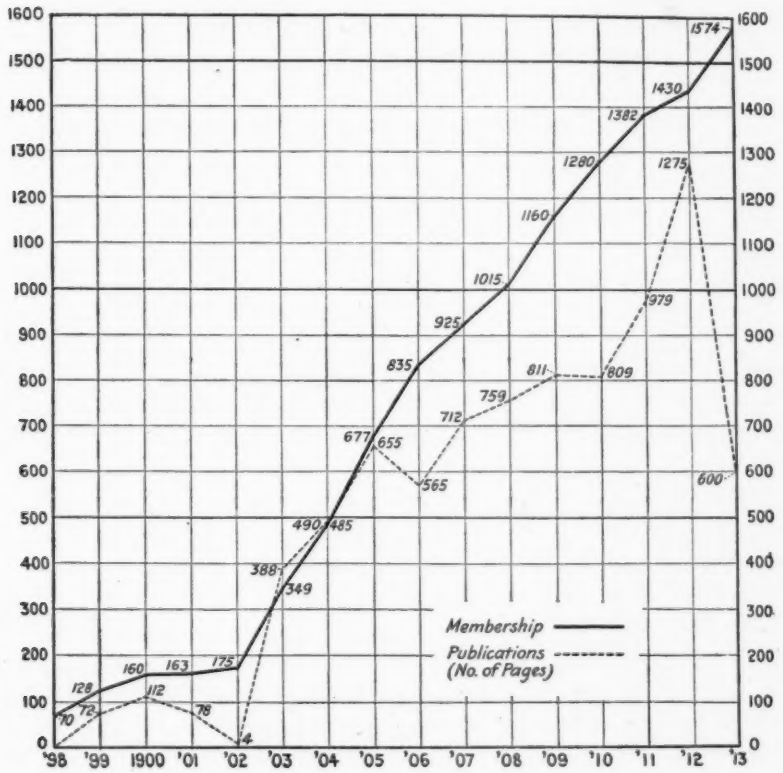
W. A. Derby.....June 30, 1912.
F. Schniewind.....March 12, 1913.
A. Bonzano.....May 5, 1913

The number of resignations is 66, and 81 members have been dropped for arrears in dues. The relatively large number of members dropped for delinquency in dues is accounted for by the fact that the number here reported includes 33 members who were in arrears at the time of the last annual meeting, but who had been granted an extension till April 1, 1912.

The net increase in the membership of the Society since the last annual meeting is 144, which is at the rate of about 115 per annum, as against an average increase of 100 for the previous six years. The present membership is 1574. It is thus seen that the doubling of the dues which went into effect on August 1, 1910, has had no detrimental influence on the growth of membership.

Publications.—With a view of stimulating the American contributions to the International Congress the last annual meeting of the Society was limited to committee reports. These reports were accordingly merged last year with the usual contents of the Year-Book and published jointly with the latter as Volume XII of the Proceedings. This accounts for the marked drop, from 1275 to 600 pages, in the publications for the year recorded in the accompanying diagram.

The Society has also recently issued a volume of 420 pages containing twenty selected standard specifications for steel and steel products in English, German, French and Spanish. In the translation into foreign languages all numeric values are given both in the British and Metric systems. The cost of this publication was defrayed from certain contributions towards



the support of the International Congress, which were influenced partly by that consideration.

The Index covering the contents of Volumes I–XII, inclusive, of the Proceedings is now in press, and every member will receive in due course a cloth-bound copy without extra charge.

There have also been issued since the last annual meeting eight official circulars of information.

The policy of preprinting committee reports and papers

and their distribution among the membership at large in advance of their presentation, which has been inaugurated this year for the first time on an extensive scale, has been rendered possible through the improved financial condition of the Society. In some instances authors have not found it possible to furnish their manuscripts sufficiently far in advance for preprinting, and in other cases the time was too limited to admit of the advance circulation of matter printed in time for the meeting. However, the results on the whole have been most encouraging and with the experience gained it is hoped that even better results will be attainable in the future. In order that the heavy cost of preprinting and circulating so large a volume of matter may be justified, it is hoped that it will result in a notable enhancement of the volume and value of written discussions, especially on the part of members who may not find it possible to attend the annual meeting. It is too early to forecast the effect of the new policy in that direction.

Technical Committees.—Committee A-9 on Alloy Steels and Committee D-3 on Standard Methods of Analysis of Fats and Oils have been discharged on their own recommendation. The functions of the committee on alloy steels, in their bearing on specifications, have been provided for through the appointment of a new sub-committee on alloy steels on the part of Committee A-1 on Standard Specifications for Steel.

With the concurrence of Committee E-2 on Uniform Specifications for Boilers, that committee has also been discharged with the understanding that all matters relating to specifications for boiler materials will hereafter be referred to the sub-committee on locomotive materials of Committee A-1.

The creation of the following new committees has been authorized by the Executive Committee:

Committee C-7 on Standard Specifications for Lime, under the chairmanship of Mr. Henry S. Spackman.

Committee D-12 on Petroleum Products, under the chairmanship of Mr. Irving C. Allen.

Committee E-2 on Electrical Standards, under the chairmanship of Mr. C. E. Skinner.

Committee E-6 on Papers, under the chairmanship of Mr. Edgar Marburg.

In view of the creation of the Committee on Papers, the previous Standing Advisory Committees on Iron and Steel, on Cast Iron, on Cement and Concrete, on Brick and Terra-Cotta Products, on Preservative Coatings, and on Tests and Testing Apparatus have been discharged.

The new Regulations Governing Technical Committees, announced last year, by which any recommendations affecting specifications must be sent in printed form to every member of the Society not less than four weeks before the annual meeting, has been strictly observed this year in connection with the following matter relating to specifications which will be presented at this meeting:

PROPOSED NEW STANDARD SPECIFICATIONS.

Recommended by Committee A-1 on Steel:

For Medium-Carbon Steel Splice Bars.
For High-Carbon Steel Splice Bars.
For Extra-High-Carbon Steel Splice Bars.
For Structural Steel for Ships.
For Rivet Steel for Ships.
For Rail-Steel Concrete Reinforcement Bars.
For Cold-Rolled Steel Axles.
For Wrought Solid Carbon-Steel Wheels for Electric Railway Service.
For Blooms, Billets and Slabs for Carbon-Steel Forgings.

Recommended by Committee A-2 on Wrought Iron:

For Wrought-Iron Plates.

Recommended by Committee B-2 on Non-Ferrous Metals:

For Electrolytic Copper Wire Bars, Cakes, Slabs, Billets, Ingots, and Ingot Bars.
For Lake Copper Wire Bars, Cakes, Slabs, Billets, Ingots, and Ingot Bars.

Recommended by Committee C-7 on Specifications for Lime:

For Lime.

Recommended by Committee D-1 on Preservative Coatings:

For the Purity of Raw Linseed Oil from North American Seed.
Standard Definitions of Terms used in Paint Specifications.

Recommended by Committee D-2 on Lubricants:

Provisional Test for Lubricants.

PROPOSED REVISIONS IN STANDARD SPECIFICATIONS.

Recommended by Committee A-1 on Steel:

For Steel Splice Bars.
For Structural Steel for Bridges.
For Structural Nickel Steel.
For Structural Steel for Buildings.
For Steel Reinforcing Bars.
For Steel Axles.
For Steel Tires.
For Steel Castings.
For Lap-Welded and Seamless Steel Boiler Tubes.
For Automobile Carbon and Alloy Steels.
For Boiler and Firebox Steel.
For Boiler Rivet Steel.
For Annealed Steel Forgings.
For Steel Shapes, Universal Mill Plates, and Bars.

Recommended by Committee A-2 on Wrought Iron:

For Refined Wrought-Iron Bars.
For Engine-Bolt Iron.

Recommended by Committee B-1 on Copper Wire:

For Hard-Drawn Copper Wire.
For Medium Hard-Drawn Copper Wire.
For Soft or Annealed Copper Wire.

As may be judged from the foregoing, the past year has been one of great activity on the part of the technical committees. Many meetings have also been held for the consideration of new and revised specifications which have not yet yielded definite returns, but from which useful results are to be anticipated in the early future.

The following additions to the Regulations Governing Technical Committees have been agreed to jointly by the Executive Committee and Committee E-5 on Rules Governing the Form but not the Substance of Specifications:

1. The insertion of the following new section after the present section on "Specifications":

Standard Definitions.—The procedure governing action on proposed new standard definitions or the proposed amendment of existing standard definitions shall be in precise conformity with that above defined in relation to "Specifications," except that such new or amended definitions shall not be referred to letter ballot of the Society prior to the annual meeting following their publication in the Proceedings of the Society.

2. The addition of the following sentence to the section on "Discharge of Committees:"

A technical committee which fails to present a report at three successive annual meetings of the Society will be required to show cause, in a written communication to the Executive Committee, why it should not be discharged.

Finances.—In the consideration of the subjoined annual report of the Treasurer it should be borne in mind that, for reasons previously stated, the period covering this report is one of about fifteen months instead of one year. The cash balance in the general funds of the Society on June 1, 1913, was $9444.39 with no outstanding liabilities except $348.35 for International dues collected since April 1, 1913.

There is perhaps no better means of judging the esteem in which the work of the Society is held in outer circles than that afforded by the returns from the sale of its publications. It is therefore especially gratifying to note that the proceeds from the sale of the publications amount to $2524.27 as compared with $982.82 from that source announced in the last annual report for the preceding period of nine months.

The unexpended balance of $1796.82 from the funds collected for Congress purposes, entered as a separate item in the cash balance, will be applied, as announced in a recent circular to members, towards the cost of binding and distributing the Proceedings of the Congress among the members of the Society.

It will be noted that the disbursements include an extraordinary item of $5000 subscribed, by authorization of the Society by letter ballot, towards the Proceedings of the International Congress, with the prospective returns, previously mentioned, to the members of the Society. It is estimated that

the balance in the treasury, together with the receipts for the remainder of the fiscal year, ending December 31, 1913, will suffice to defray the cost of the Index of Volumes I–XII, inclusive, the 1913 Year-Book, and the running expenses till the end of the year, notwithstanding the heavy outlay incurred in connection with the preprints for this meeting. The bills for this preprinting have for the most part not yet been rendered, and this item is therefore only partially accounted for among the disbursements in the report of the Treasurer.

ANNUAL REPORT OF THE TREASURER.

From March 15, 1912, to June 1, 1913.

RECEIPTS.

Membership dues	$18 048.35	
Sales of publications	2 524.27	
Orders for binding Proceedings	216.00	
Authors' reprints	93.48	
Sales of right to reprint specifications for one year	850.00	
Interest on deposits	115.47	
Unclassified receipts	16.55	
Orders for binding and extra payment required of Junior Members for International Congress Proceedings	230.50	
Special fund, for defraying cost of Selected Specifications in four languages, etc.	4 594.07	
International Association dues	2 778.68	
Total receipts	$29 467.37	
Cash balance, March 15, 1912	6 725.57	
		$36 192.94

DISBURSEMENTS.

Publications	$6 166.74	
Salaries (including Secretary's salary at the rate of $2500 per annum)	5 467.00	
Audits by public accountants	80.00	
Expenses, Secretary's office:		
Postage and expressage	$475.29	
Miscellaneous expenses	268.02	
	743.31	
Rent and insurance, storage room	171.60	
Stenographer, Fifteenth Annual Meeting	80.50	
Expenses, Fifteenth Annual Meeting	64.15	
Expenses, Sixteenth Annual Meeting	66.74	
Carried forward	$12 840.04	

Brought forward		$12 840.04	
Expenses, Technical Committees		968.52	
Special fund for defraying cost of Selected Specifications in four languages		2 797.25	
Refund of excess remittances		30.70	
Unclassified disbursements		8.50	
For account of International Association		57.65	
Remitted to International Association:			
Dues	$3 249.07		
Subscription towards Sixth Congress Proceedings	5 000.00		
		8 249.07	
Total disbursements		$24 951.73	
Cash balance, June 1, 1913:			
General funds	$9 444.39		
Special fund	1 796.82		
		11 241.21	
			$36 192.94

ANALYSIS OF DISBURSEMENTS FOR ACCOUNT OF PUBLICATIONS.

	Clerical Services.	Printing and Mailing.	Total.
Year-Book and Membership Pamphlet	$455.99	$3 620.33	$4 076.32
Proceedings	259.10	535.13	794.23
Index, Vols. I–XII	131.90	.....	131.90
Circular to Members	17.25	399.91	417.16
Preprints	.....	342.65	342.65
Reprints	.....	11.23	11.23
Miscellaneous	.....	393.25	393.25
	$864.24	$5 302.50	$6 166.74

COMMITTEE FUNDS.

COMMITTEE A-1.

Receipts		$2 391.16	
Interest on deposits		4.36	
			$2 395.52
Disbursements			2 395.52
Cash balance, June 1, 1913			$000.00

COMMITTEE D-1.

Cash balance, March 15, 1912		$193.93	
Disbursements		50.00	
Cash balance, June 1, 1913			143.93
Total cash balance, June 1, 1913			$143.93

The last report on the semi-annual audit of the books and accounts of the Society, presented on January 11, 1913, is as follows:

JOHN HEINS & CO.
PUBLIC ACCOUNTANTS AND AUDITORS.

PHILADELPHIA, January 11, 1913.

MR. EDGAR MARBURG, *Secretary and Treasurer,*
American Society for Testing Materials.

Dear Sir:

We respectfully report that we have made an audit and examination of the books and accounts of your Society for the six months ended December 31, 1912, and report them to be correct, and that the accounts are in the same excellent condition as at our last examination.

We submit balance sheet as of December 31, 1912, as also a statement of operations for the twelve months then ended, schedules of Accounts Receivable and Payable, etc.

Yours respectfully,
(Signed) JOHN HEINS & CO.

Proposed Amendment of the By-Laws.—It is recommended that Sec. 5, Art. II, of the by-laws, which was inserted last year to serve a temporary need, be stricken out.[1] The section in question reads as follows:

SEC. 5. The officers and members of the Executive Committee to hold office under these by-laws shall be as follows:

To hold office for one year:—the President elected this year (1912), the Second Vice-President, to be appointed by the Executive Committee, and the following members of the present Executive Committee: W. A. Bostwick, Robert W. Hunt, Richard Moldenke and William R. Webster.

To hold office for two years:—The First Vice-President elected this year (1912), the Secretary-Treasurer elected this year (1912), the three members of the Executive Committee elected this year (1912), and a fourth member to be appointed by the Executive Committee.

Respectfully submitted on behalf of the Executive Committee,

ROBERT W. HUNT,
President.

EDGAR MARBURG,
Secretary-Treasurer.

[1] This amendment was adopted by letter ballot of the Society on August 25, 1913.—ED.

APPENDIX.

ABSTRACT OF THE MINUTES OF THE EXECUTIVE COMMITTEE.

REGULAR MEETING, March 30, 1912.—Hotel Astor, New York City. Present: Mr. A. W. Gibbs, Vice-President; Mr. J. B. Lober, Mr. Richard Moldenke and Mr. A. A. Stevenson, members of the Executive Committee; and Mr. Edgar Marburg, Secretary-Treasurer.

The Secretary reported that favorable action had been taken on 82 applications for membership, that 37 members had resigned, and that there had been a loss of 5 members by death, making the total membership on March 15, 1912, 1430.

The Secretary presented some correspondence on the subject of charges for authors' reprints, the policy of the Society being to charge such matter to authors at net cost prices. It was decided to make no change in that policy for the present.

It was decided to authorize the creation of a new committee on Standard Specifications for Lime.

The Secretary presented some correspondence recommending the appointment of a new committee on Standard Specifications for Molding Sands and Binders. It was decided to defer action in this matter pending further developments in this field.

The question of additional appointments on the Executive Committee following the approval by letter ballot of the Society of the proposed amendments of the by-laws, was considered with the following conclusions: For Vice-President, Mr. A. N. Talbot. For membership on the Executive Committee, Mr. Chas. S. Churchill. The appointment of another member authorized by the amendment was deferred till the next meeting.

The Secretary was authorized to issue the 1912 Year-Book and the Proceedings of the Fifteenth Annual Meeting in the form of a single volume.

The Secretary submitted correspondence bearing on the recommendation that the secret ballot method should be adopted by the Society in connection with the election of officers. It was decided that if at any future time an opposition ticket should be set up, in accordance with Section 9, Article II, of the by-laws, the vote shall be by secret ballot, but that in the meantime the present method shall be adhered to.

The Secretary presented a letter under date of March 6 from the Secretary of the International Association with accompanying excerpt from the minutes of the meeting of the Council of the International Association held in Dresden on January 27, to the effect that the Council accepts the proposal of the American Society to subscribe $5000 in support of the publications of the Congress on the conditions presented in connection with the

proposal, with the added provision that members of the American Society desiring to participate in the Congress, but who are not members of the International Association, shall be enrolled as members of the latter, if only for a single year, and that the dues in the International Association to which such members would be liable for that year are to be deducted by the American Society from the subscription of $5000.

On motion the last provision added by the International Association was accepted.

REGULAR MEETING, July 11, 1912.—Engineers' Club, Philadelphia. Present: Mr. A. N. Gibbs, Vice-President; Mr. J. B. Lober, Mr. Richard Moldenke, Mr. C. E. Skinner and Mr. A. A. Stevenson, members of the Executive Committee; and Mr. Edgar Marburg, Secretary-Treasurer.

The Secretary reported that favorable action had been taken on 111 applications for membership, that 2 members had resigned, and that 33 members had been dropped for non-payment of dues, making the total membership on June 29, 1912, 1506.

The Secretary presented the resignation of Mr. W. R. Webster from membership on the Executive Committee. Mr. C. E. Skinner was elected to fill this vacancy.

Mr. G. W. Thompson was elected to another membership on the Executive Committee authorized by the amendment of the by-laws.

The Secretary presented a report from a Committee of Tellers consisting of Mr. H. H. Quimby and Mr. W. P. Taylor, on a recent letter ballot of the Society, embodying the following results:

ON AMENDMENTS OF BY-LAWS.	For Adoption	Against Adoption
Amendment of Article I	111	1
Amendment of Article II	110	1
Amendment of Article V	110	1
ON AMENDMENTS OF SPECIFICATIONS.		
Steel Splice Bars	81	2
Steel Reinforcing Bars	80	15
Magnetic Tests of Iron and Steel	63	2
ON REVISED SPECIFICATIONS.		
Heat-treated Axles	82	2
Steel Castings	72	2
Boiler and Firebox Steel	85	4
Boiler Rivet Steel	84	3
Locomotive Materials.		
Staybolt Iron	65	9

ON NEW SPECIFICATIONS.	For Adoption.	Against Adoption.
Wheels for Engine and Passenger Service	73	3
Wheels for Freight Service	75	3
Nickel Steel	81	2
Automobile Steels	78	3
Girder and High Tee Rails	72	4
Engine-bolt Iron	72	6
Refined Wrought-iron Bars	76	3
Medium Hard-drawn Copper Wire	68	4
Soft or Annealed Copper Wire	68	3
Locomotive Materials.		
Annealed Steel Forgings	81	2
Steel Boiler Tubes	72	3
Shapes, Plates, and Bars	77	3
Iron Boiler Tubes	64	7
Total number of ballots cast	137	

The Secretary called attention to the following resolution adopted at the last annual meeting of the Society:

"That the Executive Committee be requested to consider the advisability of appointing a Committee on Petroleum Products to cooperate with the International Petroleum Commission, the American Chemical Society, and the International Society of Applied Chemistry."

On motion it was decided to authorize the creation of this Committee, to be known as Committee D-12 on Petroleum Products.

The Secretary reported a proposal for merging Committee E-2 on Uniform Specifications for Boilers with Committee A-1 on Standard Specifications for Steel, with the understanding that Mr. E. D. Meier, Chairman of Committee E-2 would be invited to membership on Committee A-1 with a view of cooperating with the sub-committee on specifications for boiler materials. The Secretary stated that this proposed merger had been approved both by Committee A-1 and by Mr. Meier on behalf of Committee E-2. It was accordingly voted to approve this proposal.

On motion it was decided to amend the last paragraph in the Regulations Governing Technical Committees, which now reads:

"*Discharge of Committees.*—Technical committees may be discharged by the Executive Committee, either at their own request or with their consent, on the completion of the work for which they were appointed or in consequence of protracted inactivity."

to the following form:

"*Discharge of Committees.*—Technical committees may be discharged by the Executive Committee, either at their own request or with their consent, on the completion of the work for which they were appointed or in consequence of protracted inactivity. A technical committee which fails to present a report at three successive annual meetings of the Society will be required to

show cause why it should not be discharged in a written communication to the Executive Committee.",

with the understanding that this proposed change shall be first submitted for approval by letter ballot to Committee E-5 on Rules Governing the Form but not the Substance of Specifications.

The following resolution, adopted at the last annual meeting, on which action had been deferred at the previous meeting of the Executive Committee was considered:

"That the Executive Committee be requested to consider the advisability of submitting the standard specifications of the Society to the criticism of counsel with a view to determining their legal soundness."

It was the sense of the meeting that the proposed action was inadvisable.

The Secretary presented a circular letter under date of July 1 from the Secretary of the American Foundrymen's Association in which the following course of action was recommended:

1. To obviate the clerical labor involved in getting out a series of letters of introduction to applicants from other countries intending to visit our establishments (supposing them to have been properly accredited to us in the first place) but one general letter of introduction to be given, this to be retained by the holder until he finishes his tour.
2. No general letter of introduction to be given unless the applicant brings with him an official assurance that the European establishment he represents will be open to inspection for American visitors in return.
3. That letters accrediting visitors to our Societies should come preferably through the secretaries of our European sister societies.

It was the sense of the meeting that the recommendation in Paragraph 1 was a question that should be left to the individual judgment of the various secretaries, and that the recommendation contained in Paragraph 3 did not seem to require action by the Executive Committee. It was decided to instruct the Secretary to be governed by the recommendation in Paragraph 2 in the matter of letters of introduction to visitors from foreign countries, and to announce this action to the members of the American Society for Testing Materials in the next Circular to Members.

The Secretary presented an invitation from the President and the Committee of Organization of the Fifteenth International Congress on Hygiene and Demography to the American Society for Testing Materials to participate in that Congress. It was accordingly decided to appoint Mr. Rudolph Hering as the official delegate from the Society to that Congress.

Mr. C. E. Skinner called attention to the important work undertaken by the Standards Committee of the American Institute of Electrical Engineers in cooperation with other societies. The Secretary was accordingly instructed to accept an invitation that may come to the Society from the American Institute of Electrical Engineers to cooperate in this work, on the condition that no recommendations from that Committee would be presented for adoption by letter ballot of the Society unless they had first received the approval of the Committee representing the Society in this matter.

REGULAR MEETING, October 8, 1912.—Engineers' Club, Philadelphia. Present: Mr. A. W. Gibbs, Vice-President; Mr. Richard Moldenke, Mr.

A. A. Stevenson, Mr. S. W. Stratton and Mr. G. W. Thompson, members of the Executive Committee; and Mr. Edgar Marburg, Secretary-Treasurer.

The Secretary reported that favorable action had been taken on 44 applications for membership, and that the Society had suffered the loss of one member by death, making the total membership on September 30, 1912, 1549.

The Secretary presented a report from a Committee of Tellers consisting of Mr. H. H. Quimby and Mr. W. P. Taylor on the letter ballot of the Society on the Standard Definitions proposed by Committee D-4 on Standard Tests for Road Materials, as follows:

Number of affirmative votes	78
Number of negative votes	6
Irregular	17
Total number of votes cast	101

The Secretary reported that Committee E-5 on Regulations Governing the Form but not the Substance of Specifications had agreed by letter ballot to the amendment of the paragraph relating to "Discharge of Committees," proposed by the Executive Committee, by which the following sentence is added to that paragraph:

A technical committee which fails to present a report at three successive annual meetings of the Society will be required to show cause why it should not be discharged in a written communication to the Executive Committee.

The Secretary presented a letter signed by the members of Committee D-3 on Standard Methods of Analysis of Fats and Oils, announcing that the general committee of which that committee had been a branch had been dissolved, and recommending their own discharge. On motion that recommendation was approved.

The Secretary presented a letter from Mr. G. L. Norris, Chairman of Committee A-9 on Alloy Steels, to the effect that 14 out of 15 members of that committee had subscribed to the proposal that the committee be discharged. On motion the proposal for the discharge of Committee A-9 was approved.

The Secretary announced the receipt of a letter from the Chairman of the Standards Committee of the American Institute of Electrical Engineers expressing his personal approval of the form of the proposed cooperation between his committee and a committee from the American Society for Testing Materials, and that formal action in the premises would be taken at an early meeting of the Standards Committee, to which the Society had been invited to send a representative.

The Secretary called attention to a circular letter of protest addressed by Mr. Clifford Richardson to the members of the Executive Committee with reference to the letter ballot on Standard Definitions of Road Materials, in connection with which Mr. Richardson's minority report had not been mailed to the members of the Society.

The Secretary was instructed to notify Mr. L. W. Page, the Chairman of Committee D-4 on Standard Tests for Road Materials, and also Mr. Clifford Richardson, a member of that Committee, that it was the desire of the Executive Committee to have the Standard Definitions in question presented at the next meeting of the Society for further consideration. It was also agreed that at that time a recommendation should be offered on behalf of the Executive Committee that no action shall be taken relative to the adoption of proposed Standard Definitions until the meeting following the publication of such proposed definitions in the Proceedings of the Society.

The Secretary reported the following appointments by the President:

As representatives of the Society at the Third International Conference of Rubbergoods Manufacturers, Chemists and Engineers,

E. A. Barrier.
E. B. Tilt.

As representatives of the Society at the American Road Congress,

A. H. Blanchard.
W. W. Crosby.
R. S. Greenman.
Prévost Hubbard.
Clifford Richardson.

The Secretary presented an invitation from the American Road Builders' Association for the appointment of three delegates to the annual convention of that Association to be held in Cincinnati, December 3–6, 1912. It was decided to accept this invitation.

It was agreed that members joining the Society this year after July 1 may pay one-half of the annual dues and receive the Proceedings and Year-Book, or that they may pay the full year's dues and receive also a copy of the Sixth Congress Proceedings of the International Association.

The general question as to regulations designed to govern the acceptance and preprinting of papers was considered and it was decided:

1. That authority for the acceptance of papers shall be vested in a Committee on Papers broadly representative of the principal interests in the Society, whose membership shall be subject to enlargement under the Regulations Governing Technical Committees. This committee will also cooperate in an advisory capacity with the Secretary in the preparation of the technical program for the meetings. The Secretary of the Society shall be the chairman of the committee.

2. That this committee shall be authorized to draw up its own regulations which shall be subject to the approval of the Executive Committee. Any modifications in these regulations which may be proposed from time to time shall be similarly subject to the approval of the Executive Committee.

3. That the following appointments be made on this committee:

COMMITTEE ON PAPERS.

Edgar Marburg (Chairman).
H. C. Berry.
G. H. Clamer.
R. L. Humphrey.
Richard Moldenke.
Edgar Orton, Jr.
L. W. Page.
A. A. Stevenson.
A. N. Talbot.
S. S. Voorhees.

The above action was taken with the understanding that this committee will present its recommendations at the next quarterly meeting of the Executive Committee and that they shall not become effective until they have been approved by the Executive Committee.

It was decided that in view of the creation of the Committee on Papers, the present Standing Advisory Committees on Iron and Steel, on Cast Iron, on Cement and Concrete, on Brick and Terra-Cotta Products, on Preservative Coatings, and on Tests and Testing Apparatus be discharged.

REGULAR MEETING, January 14, 1913.—Engineers' Club, Philadelphia. Present: Mr. Robert W. Hunt, President; Mr. A. W. Gibbs and Mr. A. N. Talbot, Vice-Presidents; Mr. W. A. Bostwick, Mr. John B. Lober, Mr. Richard Moldenke, Mr. C. E. Skinner, Mr. A. A. Stevenson and Mr. G. W. Thompson, members of the Executive Committee: and Mr. Edgar Marburg, Secretary-Treasurer.

The Secretary reported that favorable action had been taken on 40 applications for membership, and that 15 members had resigned, making the total membership on January 1, 1913, 1574.

The Secretary presented correspondence in which the question was raised whether a Junior Member, though under thirty years of age, might be classed as a full Member on the payment of the added dues of $5.00 per annum.

It was decided that this arrangement could not be authorized since it is contrary to Section 2, Article I, of the By-laws, which reads "A Member shall be a person not less than thirty years of age," etc.

Mr. Stevenson in reporting on the desirability of appointing a new committee on alloy steels advised that the Executive Committee recommend to Committee A-1 the appointment of a sub-committee on alloy steel products. This suggestion was formally adopted.

The Secretary presented some correspondence recommending that committees be authorized to announce their meetings in advance in the technical press, so that non-members desiring to participate in the discussions may attend such meetings.

It was the sense of the meeting that it would be advisable to adhere to the present practice governing such matters by which non-members are privileged to attend committee meetings only on special invitation of the chairman of the committee concerned.

It was decided that the Sixteenth Annual Meeting of the Society shall be held at the Hotel Traymore, Atlantic City, N. J., on June 24–28, 1913.

Mr. Edgar Marburg, as Chairman of Committee E-6 on Papers, presented on behalf of that committee a recommendation that the Executive Committee should authorize the publication of an announcement of the regulations governing papers, committee reports and discussions in the next circular to members. The proposed regulations were read and approved and their proposed publication authorized.

The Secretary presented a letter calling attention to the apparent violation of Paragraph 6 of the Charter in the present constitution of the Executive

Committee. The Secretary was instructed to obtain legal advice in this matter.

The Secretary presented a letter under date of December 12, 1912, from the Secretary of the International Association, calling attention to Vice-President Mesnager's recent proposals that the Council's action at the Congress by which the dues were doubled should not become effective pending further consideration by the Council at its next meeting.

The Treasurer reported that he did not feel authorized to delay issuing the bills for dues at the beginning of the fiscal year, January 1, by reason of this letter. It was the sense of the meeting, as expressed informally, that the Treasurer's action in this matter was warranted.

REGULAR MEETING, April 10, 1913.—Engineers' Club, Philadelphia. Present: Mr. Robert W. Hunt, President; Mr. Richard Moldenke, Mr. C. E. Skinner and Mr. G. W. Thompson, members of the Executive Committee; and Mr. Edgar Marburg, Secretary-Treasurer.

The Secretary reported that favorable action had been taken on 56 applications for membership and that 46 members had resigned, making the total membership on April 1, 1913, 1584.

The Secretary presented correspondence with several chairmen of technical committees which resulted in the following action:

C-2, On Reinforced Concrete. Committee to be continued.
C-5, On Fireproofing Materials. Committee to be continued.
D-9, On Insulating Materials. Committee to be continued.
D-10, On Standardizing Explosives. Action to be deferred till after the annual meeting.
E-4, On Analysis of Coal. Committee to be continued.

Mr. Skinner presented a communication under date of March 3 from the Standards Committee of the American Institute of Electrical Engineers, notifying him that that committee had decided to present to the Board of Directors of the A. I. E. E. the following proposed by-law for their adoption:

"The Standards Committee of the A. I. E. E. is instructed by the Board of Directors of the A. I. E. E. to take no action on any subject matter outside of the field of electrical and magnetic standardization and within the field of the Standard Committee of another National society, before coming to an agreement with the Standards Committee of that society, provided that the said society instructs its Standards Committee not to take action in electric or magnetic standardization before coming to an agreement with the Standards Committee of the A. I. E. E."

It was stated in this communication that the Board of Directors will not be able to act upon this recommendation until their April meeting, but that "in order to avoid delay the Standards Committee urged that similar action be taken by your Society." After considerable discussion it was decided to take favorable action on this proposed by-law with a view of embodying it among the Regulations Governing Technical Committees, provided that the words "coming to," which appear twice, be changed in both instances to the single word "seeking." Mr. Skinner was authorized to so advise the A. I. E. E. Standards Committee.

The Secretary reported that in pursuance of instructions received at the last meeting he had obtained legal advice to the meaning of Paragraph 6 of the Charter, to the effect that the interpretation heretofore placed upon this paragraph by the Executive Committee is correct. It had been pointed out that if the words "at least" be inserted between the words "of" and "six" in the second line of this paragraph the meaning would be perfectly clear, the intent being that the Executive Committee shall not consist of fewer than six members.

The appointment of a Nominating Committee empowered to nominate officers and members of the Executive Committee to fill the vacancies after the next annual meeting was fully discussed and it was the sense of the meeting that it was desirable that this committee should not be a local one as heretofore. It was decided to make the following appointments on this committee:

J. P. Snow, Boston, Chairman.
Richard L. Humphrey, Philadelphia.
D. W. McNaugher, Pittsburgh.

The Secretary was authorized to announce on behalf of the Executive Committee the recommendation that Section 5 of Article II of the by-laws, which was inserted last year to serve a temporary need, shall be stricken out.

The Secretary presented a copy of the provisional program for the approaching annual meeting which was approved as to its general features with respect to the proposed number and distribution of sessions, with the understanding that the details will be left with power to Committee E-6 on Papers.

REPORT OF COMMITTEE A-1

ON

STANDARD SPECIFICATIONS FOR STEEL.

The past year has been a very active one in the affairs of this committee. The great volume and variety of work has led to an increase in the membership of the committee from 70, at the last annual meeting, to 93, and the creation of four additional sub-committees on the following subjects: Spring Steel, Methods of Chemical Analysis, Methods of Tests, and Literary Form. The total number of sub-committees is now 16. The committee has also been strengthened on the executive and administrative side by the appointment of Mr. C. D. Young as Second Vice-Chairman.

The large and growing personnel of the committee has rendered it increasingly important that the membership should be limited only to those who find it possible to participate actively in its affairs. A plan is now under consideration by which others will hereafter be automatically retired from membership.

In addition to the numerous meetings of sub-committees that have taken place during the past year the general committee has held four largely attended meetings covering nine sessions.

The committee recommends that the fourteen specifications distinguished in the following list by italics be revised in accordance with the detailed recommendations contained in Appendix I of this report,[1] and that the nine proposed new standard specifications listed below and appended to this report[2] be adopted. The proposed revision of the specifications for Structural Steel for Ships has proved so drastic that it is recommended that these specifications be cancelled and that they be superseded by the proposed new specifications Nos. 26 and 27.

[1] Pp. 67–95.
[2] Pp. 131–168.

The following is a complete list of the present standard and the proposed new specifications:

PRESENT STANDARD SPECIFICATIONS.

1. For Bessemer Steel Rails.
2. For Open-hearth Steel Rails.
3. For Open-hearth Steel Girder and High Tee Rails.
4. *For Steel Splice Bars.*
5. *For Structural Steel for Bridges.*
6. *For Structural Nickel Steel.*
7. *For Structural Steel for Buildings.*
8. For Structural Steel for Ships.
9. *For Steel Reinforcing Bars.*
10. *For Steel Axles.*
11. For Heat-Treated Carbon-Steel Axles, Shafts, and Similar Objects.
12. For Forged and Rolled, Forged, or Rolled Solid Carbon-Steel Wheels for Engine-Truck, Tender and Passenger Service.
13. For Forged and Rolled, Forged, or Rolled Solid Carbon-Steel Wheels for Freight-Car Service.
14. *For Steel Tires.*
15. For Steel Forgings.
16. *For Steel Castings.*
17. *For Lap-Welded and Seamless Steel Boiler Tubes and Safe Ends, $2\frac{1}{2}$ in. in Diameter and under.*
18. *For Automobile Carbon and Alloy Steels.*
19. *For Boiler and Firebox Steel.*
20. *For Boiler Rivet Steel.*
21. *For Annealed Steel Forgings.*
22. *For Steel Shapes, Universal Mill Plates, and Bars.*

PROPOSED NEW STANDARD SPECIFICATIONS.

23. For Medium-Carbon Steel Splice Bars.
24. For High-Carbon Steel Splice Bars.
25. For Extra-High-Carbon Steel Splice Bars.
26. For Structural Steel for Ships.
27. For Rivet Steel for Ships.

PROPOSED NEW STANDARD SPECIFICATIONS (*Continued*).

28. For Rail-Steel Concrete Reinforcement Bars.
29. For Cold-Rolled Steel Axles.
30. For Wrought Solid Carbon-Steel Wheels for Electric Railway Service.
31. For Blooms, Billets and Slabs for Carbon-Steel Forgings.

NOTE.—Reference in Appendix I to these specifications will be made in accordance with the above scheme of enumeration.

SPECIAL ANNOUNCEMENTS.

Specifications for Rails.—In its report last year the committee announced its purpose to give careful consideration during the ensuing year to the revision of the specifications for rails, and its expectation to cooperate, in that connection, with committees of other societies with a view of presenting the best possible recommendations at this meeting. The conditions during the past year have been such, however, as to render it inexpedient, in the judgment of the committee, to proceed in this matter to the extent of preparing proposed revisions of these specifications. As is well known, much serious study has recently been given to this subject in outer circles with the results of which the committee has kept in close touch. It is hoped that during the ensuing year the conditions will be such as to warrant the preparation of revised Standard Specifications for Bessemer and Open-hearth Steel Rails.

Wrought Steel Wheels.—An important experimental investigation on wrought steel wheels has been conducted during the past year at Altoona under the auspices of this committee, through its Sub-Committee VII on Rolled Steel Wheels and Steel Tires, and under the immediate direction of a special subcommittee on tests, of which Mr. G. Aertsen is chairman. The results of these tests are embodied in Appendix III to this report.[1]

Certain proposed revisions in the present Standard Specifications for Wrought Steel Wheels for Passenger and Freight Service have received careful attention at the hands of the subcommittee, but it was eventually decided to recommend no changes in these specifications at this meeting.

[1] Pp. 126–130.

Steel Forgings.—Several joint meetings of the various sub-committees interested in steel forgings have been held during the year with a view of preparing proposed revised general Standard Specifications for Forgings, but since it was not found possible to reach a unanimous agreement, it was decided to present no report at this time. This joint committee will continue its labors during the ensuing year in the expectation of presenting a definite report at the next annual meeting.

Heat-Treated Carbon-Steel Axles, etc.—It was the intention of the committee to merge the present Standard Specifications for Heat-Treated Axles, etc., with the proposed general specifications for forgings above referred to, but for reasons just stated it will be necessary to defer any recommendations concerning these specifications until the next annual meeting.

New Subjects.—The appropriate sub-committees have recently been instructed to report to the general committee on proposed Standard Specifications for (1) Structural Steel for Cars, (2) Steam Pipes, and (3) Rerolling Blooms.

The standardization of methods of chemical analysis of steel has also been entrusted to a newly created sub-committee which has been quite active but which has not yet found it possible to present a definite report. Similarly, certain questions relating to standard test specimens are under consideration by a special sub-committee.

PROPOSED REVISIONS IN PRESENT STANDARD SPECIFICATIONS.

The proposed revisions of the present standard specifications are indicated in full detail in Appendix I. Attention will be called here to only certain leading features of the proposed revisions.

In pursuance of authorization given to Committee A-1 at the last annual meeting, many of the specifications have been carefully revised as to form, as distinguished from substance, with a view of clearness and consistency. Since these changes require no action on the part of the Society they are not covered in detail in this report.

Many of the revisions recommended in this report have been made in order to avoid undesirable repetition or inconsistencies in the present specifications.

Splice Bars.—It is recommended that the title of the present specifications for "Steel Splice Bars" be changed to "Low-Carbon Steel Splice Bars" in conformity with the proposed three new specifications for splice bars. The other changes recommended in these specifications are offered mainly with a view of making these specifications consistent with the proposed new specifications.

Structural Steel for Bridges.—In pursuance of a resolution at the last annual meeting the question of introducing definite requirements as to yield point, instead of merely requiring that its value should be reported, has been considered; and it is recommended that a minimum value of one-half the ultimate tensile strength be required for the yield point.

It is further recommended that the requirements for castings shall hereafter not be embodied in these specifications, but that reference shall be made in that connection to the Standard Specifications for Steel Castings.

Reinforcing Bars.—It is recommended that the title of these specifications be changed from the present form, "Steel Reinforcing Bars," to "Billet-Steel Concrete Reinforcement Bars," in order to differentiate them definitely from the proposed new Specifications for Rail-Steel Concrete Reinforcement Bars.

Steel Axles.—These specifications have been revised with a view of making them applicable to carbon-steel car and tender axles, subject only to drop-test requirements. The committee intended to make provision for carbon-steel driving axles subject to tension tests and not to drop tests in connection with proposed new specifications for carbon-steel forgings. However, for reasons above stated in reference to steel forgings, it has been found necessary to defer the presentation of a report on these specifications till the next annual meeting.

In the revised specifications all reference to nickel-steel driving axles has been omitted.

Steel Castings.—The Specifications for Steel Castings have been thoroughly revised and extended with a view of making specific provision for castings intended for use in ship construction and in railway rolling stock construction.

Steel Tubing.—These specifications have been revised to agree with the specifications presented at the recent convention

of the Master Mechanics Association, Sub-Committee X on Steel Tubing having kept in close touch with the appropriate committee of that Association in the consideration of these specifications.[1]

Annealed Steel Forgings.—It is recommended that the title of these specifications, which form part of the standard specifications for locomotive materials, be changed from "Annealed Steel Forgings" to "Steel Forgings," inasmuch as the changes recommended include provision for unannealed forgings.

PROPOSED NEW STANDARD SPECIFICATIONS.

Splice Bars.—The committee recommends the adoption of three proposed new standard specifications for Medium-Carbon, High-Carbon, and Extra-High-Carbon Steel Splice Bars, coupled with the recommendation previously mentioned that the present Standard Specifications for Splice Bars in their proposed revised form shall be known as "Standard Specifications for Low-Carbon Steel Splice Bars."

The sub-committee on specifications for splice bars was unable to reach a unanimous agreement on the subject of camber. It was accordingly decided to make no change in this report in the present allowable camber of $\frac{1}{16}$ in. in 24 in., with the understanding that the sub-committee will make further efforts towards reaching an agreement in time for presentation at this meeting.[2]

Structural Steel and Rivet Steel for Ships.—As previously stated, the committee recommends that the present Standard Specifications for Structural Steel for Ships be cancelled and that they be substituted by the proposed new specifications for (1) Structural Steel for Ships, and (2) Rivet Steel for Ships.

The sub-committee which reported on these specifications found itself unable to reach an agreement upon the proposed revision of the table of permissible variations in weight and gage. It was accordingly decided to recommend that these

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[1] Committee A-1 was authorized by the meeting to make further revisions in these specifications (see pp. 21–22). These have been incorporated into this report, so that the revisions given on pp. 84–86 are in their finally adopted form.—ED.

[2] The sub-committee was unable to reach an agreement, and by action of the meeting Committee A-1 was instructed to report on this question at the next annual meeting.—ED.

specifications as here submitted be referred to letter ballot of the Society in anticipation of an agreement during the ensuing year as to the revision of the table in question, which would then be presented at the next annual meeting.

No provisions for castings to be used in the construction of ships have been made in the proposed new specifications, inasmuch as such provision has been made, as previously stated, in the revised Specifications for Steel Castings. An appropriate footnote to this effect has been appended to these specifications.

Rail-Steel Concrete Reinforcement Bars.—An elaborate experimental investigation on the physical properties of rail-steel concrete reinforcement bars has been conducted during the past year under the auspices of Committee A-1, acting through its Sub-Committee V on Steel Reinforcing Bars, and under the immediate direction of Prof. W. K. Hatt. The results of this important investigation, in the form of a condensed report (Appendix II)[1], will be presented to the Society at this meeting by Professor Hatt. In consequence of the facts developed by this inquiry the committee recommends the adoption of the standard specifications appended to this report (pages 153–155).

Cold-Rolled Steel Axles.—In the report on proposed Standard Specifications for Cold-Rolled Steel Axles at the last annual meeting, the committee recommended that these specifications be printed in the Proceedings but that they be not submitted to letter ballot for adoption by the Society. These specifications (pages 156–159) are now recommended for adoption as standard specifications by the Society with the following modifications:[2]

1. *Section 4* [proposed Sections 4 and 5].—Change to the following Sections 4 and 5 on "Ladle Analyses" and "Check Analyses," respectively:

> "4. An analysis shall be made by the manufacturer from a test ingot taken during the pouring of each melt, a copy of which shall be given to the purchaser or his

[1] Pp. 96-125.

[2] The specifications in their present form appear in the *Proceedings*, Am. Soc. Test. Mats., Vol. XII, p. 48 (1912). The section numbers in italics in the following list of modifications are the present numbers.

representative. This analysis shall conform to the requirements specified in Section 3.

"5. Analyses may be made by the purchaser from an axle representing each melt, which shall conform to the requirements specified in Section 3. Drillings for analysis shall be taken from the axle or from the full-size prolongation of the same, at any point midway between the center and surface."

2. *Section 6* [proposed Section 7].—Change to read:

"7. The test specimen shall bend cold through 180 deg. around a 1-in. pin or mandrel without cracking on the outside of the bent portion."

3. Omit Fig. 1, and change "Fig. 2" to "Fig. 1."

4. *Section 7* (*b*) [proposed Section 8 (*b*)].—Change the last sentence to read:

"Bend test specimens shall be $\frac{1}{2}$ in. square in section with corners rounded to a radius not over $\frac{1}{16}$ in., and need not exceed 6 in. in length."

5. Insert the following new Section 9 (*b*) under "Number of Tests":

"(*b*) If any test specimen shows defective machining or develops flaws, or if a tension test specimen breaks outside the gage length, it may be discarded and another specimen substituted."

6. *Section 9* [proposed Section 10].—Change to read:

"10. The axles shall conform to the sizes and shapes specified by the purchaser, and shall not vary more than 0.002 in. from the diameter specified. When centered, 60-deg. centers shall be used with clearance drilled for the points."

7. *Section 11* [proposed Section 12].—Change to read:

"12. Identification marks shall be legibly stamped on each axle, and on each test specimen. Unless otherwise specified, such marks shall be stamped at about the middle of the length of the axle."

8. Further proposed general changes affecting these as well as other specifications are given under "General Changes,"[1] in the items designated as follows:

(*a*) *Section 1* (*a*).—Item No. 2.
(*b*) *Section 2*.—Item No. 3.
(*c*) *Section 6* (*b*).—Item No. 6.
(*d*) *Section 10* [proposed Section 11].—Item No. 8.

Respectfully submitted on behalf of the committee,

WM. R. WEBSTER,
Chairman.

EDGAR MARBURG,
Secretary.

NOTES.—1. For the action taken on this report at the meeting, see pp. 21–23.

2. The proposed revisions recommended in fourteen present specifications, and the nine proposed new specifications, were adopted by letter ballot of the Society on August 25, 1913. The former specifications in their amended form appear in the Year-Book for 1913; the latter appear in the Year-Book and also in these Proceedings, pp. 131–168.—ED.

[For discussion of this report, see pp. 169–182.—ED.]

[1] Appendix I, pp. 93–95.

APPENDIX I.

PROPOSED CHANGES IN PRESENT STANDARD SPECIFICATIONS FOR STEEL.

In this appendix are given in detail the changes recommended in fourteen of the present standard specifications for steel and steel products. Changes which are purely matters of wording and phraseology, made by authorization given the committee at the last annual meeting, are not mentioned. The changes have been divided into two kinds: "specific changes" applying to individual specifications and "general changes" to be made in all specifications to which they apply. The specific changes are noted under the titles of the respective specifications. The reference to specifications by number is made throughout in conformity with the scheme of enumeration in the body of this report. The general changes are indicated at the end of this appendix.[1] After each change is given a list (by numbers) of the specifications and the proposed new number (in italics) of the section in which that change has been made. Where the effect of a change is the omission of an entire section, the number of the section which disappears is not given.

In order to have under one heading a complete list of the changes proposed in any specification, there is given in the last item under each specification a list of the sections in which general changes are proposed, together with the item numbers under "General Changes" in which those changes may be found.

After the title of each specification is given its page number in the 1912 Year-Book, where the specification appears in its present standard form. The section numbers in italics refer to the specifications as there printed; the proposed new section numbers, where they differ from the present numbers, are given in brackets. If the change in a section is only one of numbering, it has not been noted.

[1] Pp. 93–95.

SPECIFICATION NO. 4.—STEEL SPLICE BARS (page 127).

1. *Title.*—Change to read:

"Standard Specifications for Low-Carbon Steel Splice Bars."

2. *Section 1.*—Change to read:

"The steel may be made by the Bessemer, open-hearth, or any other process approved by the purchaser."

3. *Section 2.*—Change the requirement as to chemical composition to:

Phosphorus	Bessemer	not over 0.10 per cent
	Open-hearth	" " 0.05 "

4. *Section 3.*—Change to read:

"An analysis to determine the percentages of carbon, manganese, phosphorus and sulphur shall be made by the manufacturer from a test ingot taken during the pouring of each melt, a copy of which shall be given to the purchaser or his representative. This analysis shall conform to the requirements specified in Section 2."

5. Insert the following new Section 4 on "Check Analyses":

"4. Analyses may be made by the purchaser from finished splice bars representing each melt, in which case an excess of 25 per cent above the requirements specified in Section 2 shall be allowed."

6. *Section 4* [proposed Section 5].—In Paragraph (*a*), omit the requirement as to yield point. Omit Paragraph (*b*).

7. *Sections 8 and 10* [proposed Sections 9 and 11].—Change to read as in Specification No. 23, proposed Standard Specifications for Medium-Carbon Splice Bars, as follows:

"9. The splice bars shall be smoothly rolled, true to templet, and shall accurately fit the rails for which they are intended. The bars shall be sheared to length, and the punching and notching shall conform to the dimensions specified by the purchaser. A variation of $\frac{1}{32}$ in. from the

specified size and location of holes, and of $\frac{1}{8}$ in. from the specified length of splice bar, will be permitted. Any variation from a straight line in a vertical plane shall be such as will make the bars high in the center. The maximum camber in either plane shall not exceed $\frac{1}{16}$ in. in 24 in."

"11. The name or brand of the manufacturer and the year of manufacture shall be rolled in raised letters and figures on the side of the rolled bars, and a portion of this marking shall appear on each finished splice bar."

8. Further proposed general changes affecting these as well as other specifications are given under "General Changes" in the items designated as follows:

(*a*) *Section 5* (*b*).—Item No. 6.
(*b*) *Section 7* (*b*) [proposed Section 8 (*b*)].—Item No. 7.
(*c*) *Section 9* [proposed Section 10].—Item No. 8.
(*d*) *Section 11* [proposed Section 12].—Item No. 9.
(*e*) Proposed new Sections 13 and 14.—Items Nos. 10 and 11.

SPECIFICATION NO. 5.—STRUCTURAL STEEL FOR BRIDGES (page 129).

1. Omit the requirements as to castings [as given in Sections 2, 5, 10 (*c*), 12 (*d*), and 14 (*b*)], and insert the following new Section 1 on "Steel Castings:"

"1. The Standard Specifications for Steel Castings adopted by the American Society for Testing Materials. are hereby made a part of these specifications, and shall govern the purchase of steel castings for bridges."

with the following footnote:

"In using the Standard Specifications for Steel Castings for the purchase of castings for bridges, it is necessary to specify both the class and grade of castings desired."

2. *Sections 3 and 4* [proposed Sections 4 and 5].—Change to read:

"4. An analysis to determine the percentages of carbon, manganese, phosphorus and sulphur shall be made by the

manufacturer from a test ingot taken during the pouring of each melt, a copy of which shall be given to the purchaser or his representative. This analysis shall conform to the requirements specified in Section 3.

"5. Analyses may be made by the purchaser from finished material representing each melt, in which case an excess of 25 per cent above the requirements specified in Section 3 shall be allowed."

3. *Section 5* [proposed Section 6].—Change to read:

"6. (*a*) The material shall conform to the following requirements as to tensile properties:

Properties Considered	Structural Steel.	Rivet Steel.
Tensile strength, lb. per sq. in.	55 000 – 65 000	48 000 – 58 000
Yield point, min., " "	0.5 tens. str.	0.5 tens. str.
Elongation in 8 in., min., per cent	1 500 000[a] / Tens. str.	1 500 000 / Tens. str.
Elongation in 2 in., min., per cent	22	.....

[a] See Section 7.

"(*b*) The yield point shall be determined by the drop of the beam of the testing machine."

4. *Sections 6, 7, and 9.*—Omit.

5. *Section 10* [proposed Section 8].—Change to read:

"8. (*a*) The test specimen for plates, shapes, and bars shall bend cold through 180 deg. without cracking on the outside of the bent portion, as follows: For material $\frac{3}{4}$ in. or under in thickness, flat on itself; for material over $\frac{3}{4}$ in. to and including $1\frac{1}{4}$ in. in thickness, around a pin the diameter of which is equal to the thickness of the specimen; and for material over $1\frac{1}{4}$ in. in thickness, around a pin the diameter of which is equal to twice the thickness of the specimen.

"(*b*) The test specimen for pins and rollers shall bend cold through 180 deg. around a 1-in. pin without cracking on the outside of the bent portion.

"(*c*) The test specimen for rivet steel shall bend cold through 180 deg. flat on itself without cracking on the outside of the bent portion."

6. *Section 12* [proposed Section 10].—Change to read:

"10. (*a*) Tension and bend test specimens shall be taken from the finished rolled or forged material, and shall not be annealed or otherwise treated, except as specified in Paragraph (*b*).

"(*b*) Tension and bend test specimens for material which is to be annealed or otherwise treated before use, shall be cut from properly annealed or similarly treated short lengths of the full section of the piece.

"(*c*) Tension and bend test specimens for plates, shapes and bars, except as specified in Paragraph (*d*), shall be of the full thickness of material as rolled. They may be machined to the form and dimensions shown in Fig. 1, or with both edges parallel; except that bend test specimens for eye-bar flats may have three rolled sides.

"(*d*) Tension and bend test specimens for plates and bars (except eye-bar flats) over $1\frac{1}{2}$ in. in thickness or diameter may be machined to a thickness or diameter of at least $\frac{3}{4}$ in. for a length of at least 9 in.

"(*e*) The axis of tension and bend test specimens for pins and rollers shall be 1 in. from the surface and parallel to the axis of the bar. Tension test specimens shall be of the form and dimensions shown in Fig. 2. Bend test specimens shall be 1 by $\frac{1}{2}$ in. in section.

"(*f*) Tension and bend test specimens for rivet steel shall be of the full-size section of bars as rolled."

7. *Section 13*.—Omit; embodied in proposed Section 10 (*a*) and (*b*) [see item No. 6 above].

8. *Section 14* (*a*) [proposed Section 11 (*a*)].—Change to read:

"11. (*a*) One tension and one bend test shall be made from each melt; except that if material from one melt differs $\frac{3}{8}$ in. or more in thickness, one tension and one bend test shall be made from both the thickest and the thinnest material rolled."

9. Insert the following new Section 11 (*b*) under "Number of Tests":

"(*b*) If any test specimen shows defective machining or develops flaws, or if an 8-in. tension test specimen breaks

outside the middle third of the gage length, or if a 2-in. tension test specimen breaks outside the gage length, it may be discarded and another specimen substituted."

10. *Section 15.*—Omit.

11. *Section 17* [proposed Section 13].—Omit the sentence:

"Plates 36 in. in width and under shall have rolled edges."

12. *Section 18* [proposed Section 14].—Change to read:

"14. The name or brand of the manufacturer and the melt number shall be legibly stamped or rolled on all finished material, except that rivet and lattice bars and other small sections shall, when loaded for shipment, be properly separated and marked for identification. The identification marks shall be legibly stamped on the end of each pin and roller. The melt number shall be legibly marked, by stamping if practicable, on each test specimen."

13. *Section 19* (*a*).—Omit.

14. *Section 20* [proposed Section 16 (*b*)].—Change to read:

"(*b*) Material which shows injurious defects subsequent to its acceptance at the manufacturer's works will be rejected, and the manufacturer shall be notified."

15. Further proposed general changes affecting these as well as other specifications are given under "General Changes" in the items designated as follows:

(*a*) *Section 10* (*d*).—Item No. 6.
(*b*) *Section 17* [proposed Section 13].—Item No. 8.
(*c*) *Section 19* (*b*) [proposed Section 15].—Item No. 9.
(*d*) Proposed new Sections 16 (*a*) and 17.—Item No. 10.

SPECIFICATION NO. 0.—STRUCTURAL NICKEL STEEL (page 135).

1. *Section 2.*—Change to read:

"A sufficient discard shall be made from each ingot intended for eye bars to secure freedom from injurious piping and undue segregation."

2. *Section 6.*—(*a*) Change the heading of column 3 of the table to read: "Plates, Shapes and Bars."

(*b*) Change "Bars" in the headings of the last two columns to "Eye Bars."

(*c*) In footnote (*a*) change "bars" to "eye bars."

3. *Section 12.*—Change to read:

"(*a*) Tension and bend test specimens shall be taken from the finished rolled or forged material. Specimens for pins shall be taken after annealing.

"(*b*) Tension and bend test specimens for plates, shapes and bars, except as specified in Paragraph (*c*), shall be of the full thickness of material as rolled. They may be machined to the form and dimensions shown in Fig. 1, or with both edges parallel; except that bend test specimens shall not be less than 2 in. in width, and that bend test specimens for eye-bar flats may have three rolled sides.

"(*c*) Tension and bend test specimens for plates and bars (except eye-bar flats) over $1\frac{1}{2}$ in. in thickness or diameter may be machined to a thickness or diameter of at least $\frac{3}{4}$ in. for a length of at least 9 in.

"(*d*) The axis of tension and bend test specimens for pins and rollers shall be 1 in. from the surface and parallel to the axis of the bar. Tension test specimens shall be of the form and dimensions shown in Fig. 2. Bend test specimens shall be 1 by $\frac{1}{2}$ in. in section.

"(*e*) Tension and bend test specimens for rivet steel shall be of the full-size section of bars as rolled."

4. *Section 13* [proposed Section 13 (*a*)].—(*a*) Change the first two sentences to read:

"One tension and one bend test shall be made from each melt; except that if material from one melt differs $\frac{3}{8}$ in. or more in thickness, one tension and one bend test shall be made from both the thickest and the thinnest material rolled."

(*b*) Omit the last sentence: "No material under $\frac{5}{16}$ in. in thickness will be used."

5. Insert the following new Section 13 (*b*):

"(*b*) If any test specimen shows defective machining or develops flaws, or if an 8-in. tension test specimen breaks outside the middle third of the gage length, or if a 2-in. tension test specimen breaks outside the gage length, it may be discarded and another specimen substituted."

6. *Section 14.*—Insert under "(*a*) *When Ordered to Weight*" the following:

"For plates under 12½ lb. per sq. ft.:
Under 75 in. in width, 2.5 per cent above or below the specified weight;
75 to 100 in., exclusive, in width, 5 per cent above or 3 per cent below the specified weight;
100 in. in width or over, 10 per cent above or 3 per cent below the specified weight.",

and expand the table of allowable excess in weight to include thicknesses from ⅛ in. up—that is, replace the present table with the one as printed in Specification No. 5, Structural Steel for Bridges.

7. *Section 16.*—Change to read:

"The name or brand of the manufacturer and the melt number shall be legibly stamped or rolled on all finished material, except that rivet and lattice bars and other small sections shall, when loaded for shipment, be properly separated and marked for identification. The identification marks shall be legibly stamped on the end of each pin and roller. The melt number shall be legibly marked, by stamping if practicable, on each test specimen."

8. Further proposed general changes affecting these as well as other specifications are given under "General Changes" in the items designated as follows:

(*a*) *Section 5.*—Item No. 5.
(*b*) *Section 9* (*d*).—Item No. 6.
(*c*) *Section 15.*—Item No. 8.
(*d*) *Section 17.*—Item No. 9.
(*e*) Proposed new Sections 18 and 19.—Items Nos. 10 and 11.

SPECIFICATION NO. 7.—STRUCTURAL STEEL FOR BUILDINGS (page 141).

1. *Section 2.*—Insert a requirement for sulphur for rivet steel of "not over 0.045 per cent."

2. Insert the following new Section 4 on "Check Analyses":

"4. Analyses may be made by the purchaser from finished material representing each melt, in which case an excess of 25 per cent above the requirements specified in Section 2 shall be allowed."

3. *Section 4* (*a*) [proposed Section 5 (*a*)].—Insert a requirement for "minimum elongation in 2 in." for structural steel of "22 per cent."

4. *Sections 5 and 7.*—Omit.

5. *Section 8* [proposed Section 7].—Change to read:

"7. (*a*) The test specimen for plates, shapes and bars shall bend cold through 180 deg. without cracking on the outside of the bent portion, as follows: For material $\frac{3}{4}$ in. or under in thickness, flat on itself; for material over $\frac{3}{4}$ in. to and including $1\frac{1}{4}$ in. in thickness, around a pin the diameter of which is equal to the thickness of the specimen; and for material over $1\frac{1}{4}$ in. in thickness, around a pin the diameter of which is equal to twice the thickness of the specimen.

"(*b*) The test specimen for pins and rollers shall bend cold through 180 deg. around a 1-in. pin without cracking on the outside of the bent portion.

"(*c*) The test specimen for rivet steel shall bend cold through 180 deg. flat on itself without cracking on the outside of the bent portion."

6. *Section 9* [proposed Section 8].—Change to read:

"8. (*a*) Tension and bend test specimens shall be taken from the finished rolled or forged material, and shall not be annealed or otherwise treated, except as specified in Paragraph (*b*).

"(*b*) Tension and bend test specimens for material which is to be annealed or otherwise treated before use,

shall be cut from properly annealed or similarly treated short lengths of the full section of the piece.

"(*c*) Tension and bend test specimens for plates, shapes and bars, except as specified in Paragraph (*d*), shall be of the full thickness of material as rolled; and may be machined to the form and dimensions shown in Fig. 1, or with both edges parallel.

"(*d*) Tension and bend test specimens for plates and bars over $1\frac{1}{2}$ in. in thickness or diameter may be machined to a thickness or diameter of at least $\frac{3}{4}$ in. for a length of at least 9 in.

"(*e*) The axis of tension and bend test specimens for pins and rollers shall be 1 in. from the surface and parallel to the axis of the bar. Tension test specimens shall be of the form and dimensions shown in Fig. 2. Bend test specimens shall be 1 by $\frac{1}{2}$ in. in section.

"(*f*) Tension and bend test specimens for rivet steel shall be of the full-size section of bars as rolled."

7. Insert Fig. 2, showing the standard 2-in. tension test specimen.

8. *Section 10.*—Omit; embodied in proposed Section 8 (*a*) and (*b*) [see item No. 6 above].

9. *Section 11* [proposed Section 9].—Change to read:

"9. (*a*) One tension and one bend test shall be made from each melt; except that if material from one melt differs $\frac{3}{8}$ in. or more in thickness, one tension and one bend test shall be made from both the thickest and the thinnest material rolled.

"(*b*) If any test specimen shows defective machining or develops flaws, or if an 8-in. tension test specimen breaks outside the middle third of the gage length, or if a 2-in. tension test specimen breaks outside the gage length, it may be discarded and another specimen substituted."

10. *Section 12.*—Omit.

11. *Section 15* [proposed Section 12].—Change to read:

"12. The name or brand of the manufacturer and the melt number shall be legibly stamped or rolled on all fin-

ished material, except that rivet and lattice bars and other small sections shall, when loaded for shipment, be properly separated and marked for identification. The identification marks shall be legibly stamped on the end of each pin and roller. The melt number shall be legibly marked, by stamping if practicable, on each test specimen."

12. Further proposed general changes affecting these as well as other specifications are given under "General Changes" in the items designated as follows:

(*a*) *Section 3.*—Item No. 4.
(*b*) *Section 8* (*c*).—Item No. 6.
(*c*) *Section 14* [proposed Section 11].—Item No. 8.
(*d*) *Section 16* [proposed Section 13].—Item No. 9.
(*e*) Proposed new Sections 14 and 15.—Items Nos. 10 and 11.

SPECIFICATION NO. 9.—STEEL REINFORCING BARS (page 161).

1. *Title.*—Change to read:

"Standard Specifications for Billet-Steel Concrete Reinforcement Bars."

2. *Section 12* (*a*).—Change to read:

"One tension and one bend test shall be made from each melt of open-hearth steel, and from each melt, or lot of ten tons, of Bessemer steel; except that if material from one melt differs $\frac{3}{8}$ in. or more in thickness or diameter, one tension and one bend test shall be made from both the thickest and the thinnest material rolled."

3. *Section 13.*—Omit.

4. *Section 16* [proposed Section 15].—Add the following sentence:

"15. All tests (except check analyses) and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works."

5. Further proposed general changes affecting these as well as other specifications are given under "General Changes" in the items designated as follows:

(*a*) *Section 6.*—Item No. 4.
(*b*) *Section 7.*—Item No. 5.
(*c*) *Section 10* (*b*).—Item No. 6.
(*d*) *Section 12* (*b*).—Item No. 7.
(*e*) *Section 15* [proposed Section 14].—Item No. 8.
(*f*) Proposed new Sections 16 and 17.—Items Nos. 10 and 11.

SPECIFICATION NO. 10.—STEEL AXLES (page 165).

1. *Title.*—Change to read:

"Standard Specifications for Carbon-Steel Car and Tender Axles."

2. *Sections 1 and 2.*—Omit.

3. *Section 4* [proposed Section 2].—Change the requirements as to chemical composition to read:

Carbon	0.35 – 0.55 per cent
Manganese	not over 0.70 "
Phosphorus	" " 0.05 "
Sulphur	" " 0.06 "

4. *Section 5* [proposed Sections 3 and 4].—Change to the following Sections 3 and 4 on "Ladle Analyses" and "Check Analyses", respectively:

"3. An analysis shall be made by the manufacturer from a test ingot taken during the pouring of each melt, a copy of which shall be given to the purchaser or his representative. This analysis shall conform to the requirements specified in Section 2.

"4. Analyses may be made by the purchaser from an axle representing each melt, which shall conform to the requirements specified in Section 2. Drillings for analysis shall be taken from the axle or from the full-size prolongation of the same, at any point midway between the center and surface."

5. *Section 6.*—Omit.

6. *Section 7* [proposed Section 5].—(*a*) Omit the sentence: "The car and tender-truck axles shall conform to the following drop test requirements."

(*b*) After "fifth", line 6, insert "and seventh."

(*c*) In the table, change the last three figures in the last column—8, 7 and $5\frac{1}{2}$—to $7\frac{3}{4}$, $6\frac{1}{2}$ and 5, respectively.

(*d*) Add the following requirements to the table:

Diameter of axle, in.	$6\frac{7}{16}$
Distance between supports, ft.	3
Weight of tup, lb.	1640
Height of drop, ft.	43
Number of blows.	9
Max. deflection after first blow, in.	$3\frac{1}{2}$

7. *Section 9.*—Omit.

8. *Section 10* [proposed Section 7].—Change to read:

"7. One drop test shall be made from each melt."

9. *Section 11* [proposed Section 8].—Change to read:

"8. The axles shall conform to the sizes and shapes specified by the purchaser. When centered, 60-deg. centers shall be used with clearance drilled for the points."

10. *Section 13* [proposed Section 10].—Change to read:

"10. Identification marks shall be legibly stamped on each axle; but such marks shall not be stamped at any point on the body of the axle between the rough collars."

11. Further proposed general changes affecting these as well as other specifications are given under "General Changes" in the items designated as follows:

(*a*) *Section 12* [proposed Section 9].—Item No. 8.
(*b*) *Section 14* [proposed Section 11].—Item No. 9.
(*c*) Proposed new Sections 12 and 13.—Items Nos. 10 and 11.

SPECIFICATION NO. 14.—STEEL TIRES (page 184).

1. *Section 5 (a) and (b)* [proposed Sections 5 and 6].—Replace by the following Sections 5 and 6 on "Ladle Analyses" and "Check Analyses," respectively:

"5. An analysis to determine the percentages of carbon, manganese, phosphorus, sulphur and silicon shall be made by the manufacturer from a test ingot taken during the pouring of each melt, a copy of which shall be given to the purchaser or his representative. This analysis shall conform to the requirements specified in Section 4.

"6. Analyses may be made by the purchaser from a tire or a tension test specimen representing each melt, which shall conform to the requirements as to phosphorus and sulphur specified in Section 4."

2. *Section 8 (a)* [proposed Section 9 (*a*)].—Change the first sentence to read:

"Tension test specimens shall be taken from test bars which shall receive as nearly as practicable the same amount of work as the tires which they represent."

3. *Section 8 (b)* [proposed Section 9 (*b*)].—Omit "cold," line 2.

4. *Section 9* [proposed Section 10].—Change to read:

"10. The drop test tire shall be selected by the inspector, and furnished at the expense of the purchaser if it conforms to the requirements specified."

5. *Section 11* [proposed Section 12].—Change to read:

"12. If the results of the physical tests of any melt do not conform to the requirements specified, retests on two additional tires from the same melt may be made at the expense of the manufacturer, each of which shall conform to the requirements specified."

6. *Section 13* [proposed Section 14].—Change to read:

"14. The tires shall be free from injurious defects and shall have a workmanlike finish."

7. *Section 14* [proposed Section 15].—Insert "of the manufacturer," line 1, between "number" and "shall," line 2.

8. *Section 16* [proposed Section 17 (*b*)].—Change "replace them at this own expense" to read: "be notified."

9. Further proposed general changes affecting these as well as other specifications are given under "General Changes" in the items designated as follows:

(*a*) *Section 15* [proposed Section 16].—Item No. 9.
(*b*) Proposed new Sections 17 (*a*) and 18.—Item No. 10.

SPECIFICATION NO. 16.—STEEL CASTINGS (page 192).

1. Insert the following new Section 3 on "Basis of Purchase":

> "3. The purchaser shall indicate his intention to substitute the test to destruction specified in Section 11 for the tension and bend tests, and shall designate the patterns from which castings for this test shall be made."

2. *Section 4* (*b*) [proposed Section 5 (*b*)].—Change to read:

> "(*b*) Class B castings shall be allowed to become cold. They shall then be uniformly reheated to the proper temperature to refine the grain (a group thus reheated being known as an "annealing charge"), and allowed to cool uniformly and slowly. If, in the opinion of the purchaser or his representative, a casting is not properly annealed, he may at his option require the casting to be re-annealed."

3. *Section 5* [proposed Section 6].—Change the requirement for phosphorus of Class A castings from "not over 0.08 per cent" to "not over 0.06 per cent."

4. *Section 7.*—Change to Section 8 (*b*) and insert the following new Section 8 (*a*) on "Check Analyses:"

> "8. (*a*) Analyses of Class A castings may be made by the purchaser, in which case an excess of 20 per cent above the requirement as to phosphorus specified in Section 6 shall be allowed. Drillings for analysis shall be taken not less than $\frac{1}{4}$ in. beneath the surface."

5. Insert under "III. Physical Properties and Tests" the words "(For Class B Castings only)", and omit all further reference to "Class B" under this Sub-Title.

6. *Section 9.*—Change to Section 10 (*a*), and add the following new Section 10 (*b*):

"(*b*) Hard castings shall not be subject to bend test requirements."

7. *Section 11* (*a*) [proposed Section 12 (*a*) and (*b*)].—Change to read:

"12. (*a*) Sufficient test bars, from which the test specimens required in Section 13 (*a*) may be selected, shall be attached to castings weighing 500 lb. or over, when the design of the castings will permit. If the castings weigh less than 500 lb., or are of such a design that test bars cannot be attached, two test bars shall be cast to represent each melt; or the quality of the castings shall be determined by tests to destruction as specified in Section 11. All test bars shall be annealed with the castings they represent.

"(*b*) The manufacturer and purchaser shall agree whether test bars can be attached to castings, on the location of the bars on the castings, on the castings to which bars are to be attached, and on the method of casting unattached bars."

8. *Section 11* (*b*) [proposed Section 12 (*c*)].—Change the last sentence to read:

"Bend test specimens shall be machined to 1 by $\frac{1}{2}$ in. in section with corners rounded to a radius not over $\frac{1}{16}$ in."

9. *Section 12* (*a*) [proposed Section 13 (*a*)].—Change to read:

"13. (*a*) One tension and one bend test shall be made from each annealing charge. If more than one melt is represented in an annealing charge, one tension and one bend test shall be made from each melt."

10. Insert the following new Section 15 (*b*) under "Finish":

"(*b*) Minor defects which do not impair the strength of the castings may, with the approval of the purchaser or his representative, be welded by an approved process. The defects shall first be cleaned out to solid metal; and after

welding, the castings shall be annealed, if specified by the purchaser or his representative."

11. *Section 16* [proposed Section 17 (*b*)].—Change the phrase "before or after machining" to read: "subsequent to their acceptance at the manufacturer's works."

12. Insert the following new special requirements for castings for ships:

"VI. SPECIAL REQUIREMENTS FOR CASTINGS FOR SHIPS.

"19. In addition to the preceding requirements, castings for ships, when so specified, shall conform to the following requirements:

"20. All castings shall be annealed.

"21. (*a*) One tension and one bend test shall be made from each of the following castings: stern frames, stern posts, twin screw spectacle frames, propellor shaft brackets, rudders, steering quadrants, tillers, stems, anchors, and other castings when specified.

"(*b*) When a casting is made from more than one melt, four tension and four bend tests shall be made from each casting.

"22. (*a*) A percussion test shall be made on each of the following castings: stern frames, stern posts, twin screw spectacle frames, propellor shaft brackets, rudders, steering quadrants, tillers, stems, anchors, and other castings when specified.

"(*b*) For this test, the casting shall be suspended by chains and hammered all over with a hammer of a weight approved by the purchaser or his representative. If cracks, flaws, defects, or weakness appear after such treatment, the casting will be rejected."

13. Insert the following new special requirements for castings for railway rolling stock:

"VII. SPECIAL REQUIREMENTS FOR CASTINGS FOR RAILWAY ROLLING STOCK.

"23. Castings for railway rolling stock, when so specified, shall conform to the requirements for Class B castings, Sections 1 to 18, inclusive, except that check analyses made in accordance with Section 8 (*b*) shall conform to the requirements as to phosphorus and sulphur specified in Section 6."

14. Further proposed general changes affecting these as well as other specifications are given under "General Changes" in the items designated as follows:

(*a*) *Section 3* [proposed Section 4].—Item No. 2.
(*b*) *Section 6* [proposed Section 7].—Item No. 4.
(*c*) *Section 7* [proposed Section 8 (*b*)].—Item No. 5.
(*d*) *Section 15* [proposed Section 16].—Item No. 9.
(*e*) Proposed new Sections 17 (*a*) and 18.—Item No. 10.

SPECIFICATION NO. 17.—LOCOMOTIVE MATERIALS: LAP-WELDED AND SEAMLESS STEEL BOILER TUBES (page 258).[1]

1. *Title.*—Change to read:

"Locomotive Materials: Lap-Welded and Seamless Steel Boiler Tubes, Safe Ends, and Arch Tubes."

2. *Section 2.*—Change the carbon requirement from "not over 0.15 per cent" to "0.08–0.18 per cent."

3. *Section 3* (*a*).—Change "shall be made" to read: "may be made by the purchaser."

4. *Section 4* [proposed Section 4 (*a*)].—Change to read:

"4. (*a*) A test specimen not less than 4 in. in length shall have a flange turned over at right angles to the body of the tube, without showing cracks or flaws. This flange, as measured from the outside of the tube, shall be $\frac{3}{8}$ in. wide for tubes $2\frac{1}{2}$ in. or under in outside diameter, and $\frac{1}{2}$ in. wide for tubes over $2\frac{1}{2}$ in. in outside diameter."

5. Insert the following new Section 4 (*b*):

"(*b*) In making the flange test, it is recommended that the flaring tool and die block shown in Fig. 1 be used."

6. *Section 6.*—Change to read:

"A test specimen $2\frac{1}{2}$ in. in. length shall stand crushing longitudinally until the outside folds are in contact, without showing cracks or flaws."

[1] The additional changes given on pp. 21–22, authorized at the meeting, have been included in this list.—ED.

7. *Section 7.*—Change to read:

"Tubes under 5 in. in diameter shall stand an internal hydraulic pressure of 1000 lb. per sq. in.; and tubes 5 in. or over in diameter shall stand an internal hydraulic pressure of 800 lb. per sq. in."

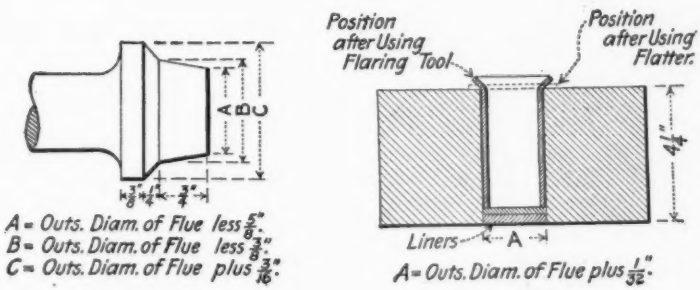


FIG. 1.

8. *Section 8 (a).*—Change the first sentence to read:

"Test specimens shall consist of sections cut from tubes selected by the inspector representing the purchaser from the lot offered for shipment."

9. *Section 10.*—Insert "from any lot" after "tube," line 1.

10. *Section 11.*—Replace the present table of standard weights by the following one:

THICKNESS.		WEIGHT, LB. PER FT. OF LENGTH. Outside Diameter, in.												
In.	Nearest B. w. g.	1¾	2	2¼	2½	3	3½	4	4½	5	5¼	5⅜	5½	6
0.095	13	1.68	1.93	2.19	2.44	....	....	....	....	....	....	....	....	....
0.110	12	1.93	2.22	2.51	2.81	3.40	....	....	....	....	....	....	....	....
0.125	11	2.17	2.50	2.84	3.17	3.84	4.51	....	....	....	....	....	....	....
0.135	10	2.33	2.69	3.05	3.41	4.13	4.85	5.57	....	....	....	....	....	....
0.150	9	2.56	2.95	3.36	3.76	4.57	5.37	6.17	6.97	7.77	8.17	8.37	8.57	9.37
0.165	8	....	....	....	4.11	5.00	5.88	6.76	7.64	8.52	8.96	9.18	9.40	10.28
0.180	7	....	....	....	4.46	5.42	6.38	7.34	8.30	9.27	9.75	9.99	10.23	11.19

11. *Section 13 (a) and (b)* [proposed Section 13].—Change to read:

"13. The finished tubes shall be circular within 0.02 in., and the mean outside diameter shall not vary more than 0.015 in. from the size ordered. The thickness at any point shall not vary more than 10 per cent from that specified. The length shall not be under, but may be 0.125 in. over that ordered."

12. *Section 15.*—Change to read:

"The name or brand of the manufacturer, and 'Tested at 1000 lb.' for tubes under 5 in. in diameter, and 'Tested at 800 lb.' for tubes 5 in. or over in diameter, shall be legibly stenciled in white on each tube."

13. Further proposed general changes affecting these as well as other specifications are given under "General Changes" in the items designated as follows:

(*a*) *Section 14.*—Item No. 8.
(*b*) *Section 16.*—Item No. 9.
(*c*) Proposed new Sections 17 (*a*) and 18.—Item No. 10.

SPECIFICATION NO. 18.—AUTOMOBILE CARBON AND ALLOY STEELS (page 196).

1. *Section 2 (a).*—Omit.

2. *Section 3.*—Omit the last sentence.

3. *Section 7 (f) and (g).*—Omit.

4. *Sections 12, 13 and 14* [proposed Section 12].—Change to read:

"12. (*a*) Tension and bend test specimens shall be taken from the rolled or forged material; except that in the case of irregularly shaped forgings, they may be taken from a full-size prolongation. Specimens shall not be annealed or otherwise treated, except as specified in Paragraph (*b*).

"(*b*) Tension and bend test specimens for material which is to be annealed or otherwise treated before use, shall be cut from properly annealed or similarly treated short lengths of the full section of the piece.

"(*c*) Tension and bend test specimens for plates and shapes shall be of the full thickness of material as rolled; and may be machined to the form and dimensions shown in Fig. 1, or with both edges parallel.

"(*d*) Tension and bend test specimens for rolled bars and forgings of uniform cross-section $1\frac{1}{2}$ in. or under in thickness or diameter, may be of the full-size section of material as rolled or forged, or may be machined to a thickness or diameter of at least $\frac{3}{4}$ in. for a length of at least 9 in. Tension test specimens shall be of 8-in. gage length.

"(*e*) The axis of tension and bend test specimens for rolled bars and forgings of uniform cross-section over $1\frac{1}{2}$ in. in thickness or diameter, and for forgings of irregular sections, when practicable, shall be located at any point midway between the center and surface and shall be parallel to the axis of the piece in the direction in which the metal is most drawn out. Tension test specimens shall be of the form and dimensions shown in Fig. 2. Bend test specimens shall be $\frac{1}{2}$ in. square in section with corners rounded to a radius not over $\frac{1}{16}$ in., and need not exceed 6 in. in length."

5. Change "Fig. 1" to "Fig. 2," and "Fig. 2" to "Fig. 1."

6. *Section 15* [proposed Section 13].—Change to read:

"13. (*a*) One tension and one bend test shall be made from each melt; except that if material rolled from one melt differs $\frac{3}{8}$ in. or more in thickness, one tension and one bend test shall be made from both the thickest and the thinnest material.

"(*b*) If any test specimen shows defective machining or develops flaws, or if an 8-in. tension test specimen breaks outside the middle third of the gage length, or if a 2-in. tension test specimen breaks outside the gage length, it may be discarded; in which case the manufacturer and the purchaser or his representative shall agree upon the selection of another specimen in its stead."

7. *Section 16.*—Omit.

8. Insert the sub-title "IV. Finish" and the following new Section 14 on "Finish":

"14. The material shall be free from injurious defects and shall have a workmanlike finish."

9. Further proposed general changes affecting these as well as other specifications are given under "General Changes" in the items designated as follows:

(*a*) *Section 3.*—Item No. 2.
(*b*) *Section 4.*—Item No. 3.
(*c*) *Section 7.*—Item No. 5.
(*d*) *Section 11* (*b*).—Item No. 6.
(*e*) Proposed new Section 16 (*b*).—Item No. 11.

SPECIFICATION NO. 19.—BOILER AND FIREBOX STEEL (page 152).

1. Proposed general changes affecting these as well as other specifications are given under "General Changes" in the items designated as follows·

(*a*) *Section 5.*—Item No. 5.
(*b*) *Section 8* (*c*).—Item No. 6.
(*c*) *Section 11* (*b*).—Item No. 7.
(*d*) *Section 13.*—Item No. 8.
(*e*) *Section 15.*—Item No. 9.
(*f*) Proposed new Sections 16 and 17.—Items Nos. 10 and 11.

SPECIFICATION NO. 20.—BOILER RIVET STEEL (page 157).

1. *Section 8* [proposed Section 8 (*a*)].—Add the following clause:

", each of which shall conform to the requirements specified."

2. Insert the following new Section 8 (*b*):

"(*b*) If any test specimen develops flaws, or if a tension test specimen breaks outside the middle third of the gage length, it may be discarded and another specimen substituted."

3. *Section 12.*—Change to read:

"Rivet bars shall, when loaded for shipment, be properly separated and marked with the name or brand of the manufacturer and the melt number for identification. The melt number shall be legibly marked on each test specimen."

4. *Section 17* (*a*) [proposed Section 19 (*a*)].—Change to read:

"19. (*a*) When specified, one tension test shall be made from each size in each lot of rivets offered for inspection."

5. *Section 17* (*b*) [proposed Section 19 (*b*)].—Add the following clause:

", each of which shall conform to the requirements specified."

6. *Section 19* [proposed Section 21].—Change to read:

"21. The finished rivets shall be free from injurious defects."

7. Insert the following new Section 22 on "Inspection":

"22. The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the rivets ordered. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the rivets are being furnished in accordance with these specifications. All tests and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works."

8. *Section 20* [proposed Section 23].—Replace by the following standard section on "Rejection":

"23. Rivets which show injurious defects subsequent to their acceptance at the manufacturer's works will be rejected, and the manufacturer shall be notified."

9. Further proposed general changes affecting these as well as other specifications are given under "General Changes" in the items designated as follows:

(*a*) *Section 3.*—Item No. 4.
(*b*) *Section 4.*—Item No. 5.
(*c*) *Section 6* (*c*).—Item No. 6.
(*d*) *Section 11.*—Item No. 8.
(*e*) *Section 13.*—Item No. 9.
(*f*) Proposed new Sections 14 and 15.—Items Nos. 10 and 11.

SPECIFICATION NO. 21.—LOCOMOTIVE MATERIALS: ANNEALED STEEL FORGINGS (page 250).

1. *Title.*—Omit "Annealed."

2. Insert the following new Section 1 on "Basis of Purchase:"

"1. (*a*) These specifications cover unannealed and annealed steel forgings up to and including 12 in. in thickness or diameter.

"(*b*) The manufacturer may, at his option, furnish annealed forgings when unannealed forgings are specified by the purchaser, provided they conform to the requirements specified for unannealed forgings."

3. *Section 2* [proposed Section 3].—Change to read:

"3. When annealed, the forgings shall be allowed to become cold after forging. They shall then be uniformly reheated to the proper temperature to refine the grain, and allowed to cool uniformly and slowly."

4. *Section 6* (*a*) [proposed Section 7 (*a*)].—Change the minimum requirements as to tensile properties to read as follows:

	UNANNEALED.	ANNEALED.
Tensile strength, lb. per sq. in.....	80 000	80 000
Yield point, lb. per sq. in.....0.5 tens. str.		0.5 tens. str.
Elongation in 2 in., per cent.....	20	22
Reduction of area, per cent.....	25	30

5. Insert the following new Section 8 (*a*) on "Bend Tests:"

"8. (*a*) Unannealed forgings shall not be subject to bend test requirements."

6. *Section 7* (*a*) [proposed Section 8 (*b*)].—Insert "for annealed forgings" after "specimen," line 1.

7. *Section 8* (*b*) [proposed Section 9 (*b*)].—Change the second sentence to read:

"Bend test specimens shall be $\frac{1}{2}$ in. square in section with corners rounded to a radius not over $\frac{1}{16}$ in., and need not exceed 6 in. in length."

8. Insert the following new Section 10 (*b*) under "Number of Tests:"

"(*b*) If any test specimen shows defective machining or develops flaws, or if a tension test specimen breaks outside the gage length, it may be discarded and another specimen substituted."

9. *Section 10* [proposed Section 11].—Insert "anneal or" before "re-anneal," line 3.

10. Further proposed general changes affecting these as well as other specifications are given under "General Changes" in the items designated as follows:

(*a*) *Section 4* [proposed Section 5].—Item No. 4.
(*b*) *Section 5* [proposed Section 6].—Item No. 5.
(*c*) *Section 7* (*b*).—Item No. 6.
(*d*) *Section 12* [proposed Section 13].—Item No. 8.
(*e*) Proposed new Section 16 (*b*).—Item No. 11.

SPECIFICATION NO. 22.—LOCOMOTIVE MATERIALS: STEEL SHAPES, UNIVERSAL MILL PLATES, AND BARS (page 254).

1. *Section 7.*—In line 3, change "under $\frac{3}{4}$ in." to "$\frac{3}{4}$ in. or under." In line 4, change "$\frac{3}{4}$ to $1\frac{1}{4}$ in." to "over $\frac{3}{4}$ in. to and including $1\frac{1}{4}$ in."

2. *Section 9.*—Change to read:

"(*a*) Tension and bend test specimens shall be taken from the finished rolled material.

"(*b*) Tension and bend test specimens, except as specified in Paragraph (*c*), shall be of the full thickness of material as rolled; and may be machined to the form and dimensions shown in Fig. 1, or with both edges parallel.

"(*c*) Tension and bend test specimens for plates and bars over $1\frac{1}{2}$ in. in thickness or diameter may be machined to a thickness or diameter of at least $\frac{3}{4}$ in. for a length of at least 9 in."

3. *Section 10* (*a*).—Omit "At least."

4. *Section 13.*—Change to read:

"The name or brand of the manufacturer and the melt number shall be legibly stamped or rolled on all finished material, except that small sections shall, when loaded for shipment, be properly separated and marked for identification. The melt number shall be legibly marked, by stamping if practicable, on each test specimen."

5. *Section 15* [proposed Section 15 (*b*)].—Change to read:

"(*b*) Material which shows injurious defects subsequent to its acceptance at the manufacturer's works, or after inspection in accordance with Section 14 (*b*), will be rejected, and the manufacturer shall be notified."

6. Further proposed general changes affecting these as well as other specifications are given under "General Changes" in the items designated as follows:

(*a*) *Section 3.*—Item No. 4.
(*b*) *Section 4.*—Item No. 5.
(*c*) *Section 7* (*b*).—Item No. 6.
(*d*) *Section 10* (*b*).—Item No. 7.
(*e*) *Section 12.*—Item No. 8.
(*f*) *Section 14* (*a*).—Item No. 9.
(*g*) Proposed new Sections 15 (*a*) and 16.—Item No. 10.

GENERAL CHANGES.

1. Changes which are purely matters of wording and phraseology have not been noted in the following.

The numbers of the specifications affected, with the proposed new section numbers (in italics), are given after each change, except when other changes have been made in a given section and the proposed new or revised wording appears in the previous list of specific changes.

MANUFACTURE.

2. *Process.*—Change the phrase "or any other approved process," to read "or any other process approved by the purchaser."

No. 16, *4;* No. 18, *3;* No. 29, *1* (*a*).

3. *Discard.*—In all specifications in which a section on discard appears, excepting Specification No. 6 (see page 72), use the following:

> "A sufficient discard shall be made from each ingot to secure freedom from injurious piping and undue segregation."

No. 18, *4;* No. 29, *2.*

CHEMICAL PROPERTIES AND TESTS.

4. *Ladle Analyses.*—The determination of the percentages of carbon, manganese, phosphorus and sulphur in ladle analyses is to be added to all specifications in which only phosphorus and sulphur are specified under "Chemical Composition."

This requires the addition of the phrase "to determine the percentages of carbon, manganese, phosphorus and sulphur" to the "Ladle Analyses" section of the following specifications:

No. 7, *3;* No. 9, *6;* No. 16, *7;* No. 20, *3;* No. 21, *5;* No. 22, *3.*

5. *Check Analyses.*—In the sentence

> "A check analysis may be made by the purchaser from finished material representing each melt, . . ."

the words "A check analysis" are to be replaced by the word "Analyses" in all specifications.

No. 6, *5;* No. 9, *7;* No. 16, *8* (*b*); No. 18, *7*; No. 19, *5;* No. 20, *4;* No. 21, *6;* No. 22, *4.*

PHYSICAL PROPERTIES AND TESTS.

6. *Bend Tests.*—The following sentence is to be omitted from all specifications in which it occurs:

"Bend tests may be made by pressure or by blows."

Nos. 4, 5, 6, 7, 9, 18, 19, 20, 21, 22, 29.

7. *Number of Tests.*—The phrase "shows defective machining or" is to be added after the word "specimen" in the paragraph of this section in all specifications providing for a possible retest of defective test specimens, excepting specifications Nos. 20 and 27 in which specimens are tested as rolled. Thus:

"If any test specimen *shows defective machining or* develops flaws, or if a tension test specimen . . . ."

No. 4, *8* (*b*); No. 9, *12* (*b*); No. 19, *11* (*b*); No. 22, *10* (*b*).

WORKMANSHIP AND FINISH.

8. *Finish.*—In all specifications containing the following section on "Finish":

"The . . . shall be free from injurious seams, slivers, flaws and other defects, and shall have a workmanlike finish.",

the words "seams, slivers, flaws and other" are to be omitted.

No. 4, *10;* No. 5, *13;* No. 6, *15;* No. 7, *11;* No. 9, *14;* No. 10, *9;* No. 17, *14;* No. 19, *13;* No. 20, *11;* No. 21, *13;* No. 22, *12;* No. 29, *11.*

INSPECTION AND REJECTION.

9. *Inspection.*—In the following sentence[1] of the standard section on inspection:

"All tests and inspection shall be made at the place of manufacture prior to shipment, and shall be so conducted as not to interfere unnecessarily with the operation of the works.",

(1) insert "(except check analyses)" after "tests" in all speci-

[1] This sentence does not appear in those sections on inspection which provide definitely that "the purchaser may make the tests to govern the acceptance or rejection of material in his own laboratory or elsewhere."

fications containing requirements as to check analyses; (2) add "unless otherwise specified," after "shipment."

No. 4, *12;* No. 5, *15;* No. 6, *17;* No. 7, *13;* No. 10, *11;* No. 14, *16;* No. 16, *16;* No. 17, *16;* No. 19, *15;* No. 20, *13;* No. 22, *14* (*a*).

10. *Rejection and Rehearing.*—Insert the following sections in all specifications specifying "check analyses":

> "Unless otherwise specified, any rejection based on tests made in accordance with Section —[1] shall be reported within five working days from the receipt of samples."
>
> "Samples tested in accordance with Section —,[1] which represent rejected material, shall be preserved for two weeks from the date of the test report. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time."

No. 4, *13* (*a*), *14;* No. 5, *16* (*a*), *17;* No. 6, *18* (*a*), *19;* No. 7, *14* (*a*), *15;* No. 9, *16* (*a*), *17;* No. 10, *12* (*a*), *13;* No. 14, *17* (*a*), *18;* No. 16, *17* (*a*), *18;* No. 17, *17* (*a*), *18;* No. 19, *16* (*a*), *17;* No. 20, *14* (*a*), *15;* No. 22, *15* (*a*), *16.*

11. *Rejection.*—In all specifications not providing for the rejection of defective material after its acceptance at the manufacturer's works, the following requirement is to be added:

> "Material [that is, splice bars, wheels, etc.] which shows injurious defects *subsequent to its acceptance at the manufacturer's works* [or *while being finished by the purchaser*] will be rejected, and the manufacturer shall be notified."

No. 4, *13* (*b*); No. 6, *18* (*b*); No. 7, *14* (*b*); No. 9, *16* (*b*); [No. 10, *12* (*b*)]; [No. 18, *16* (*b*)]; No. 19, *16* (*b*); No. 20, *14* (*b*); [No. 21, *16* (*b*)].

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[1] This section number is that of the section on "Check Analyses."

APPENDIX II.

CONDENSED REPORT OF THE INVESTIGATION OF REINFORCING BARS REROLLED FROM STEEL RAILS

CONDUCTED UNDER INSTRUCTIONS FROM SUB-COMMITTEE V, ON STEEL REINFORCING BARS, OF COMMITTEE A-1.

BY W. K. HATT.

GENERAL.

Prefatory Note.—This publication is condensed from the official report to Sub-Committee V, on Steel Reinforcing Bars, of Committee A-1 by the omission of several appendices that contained the laboratory logs, calculation sheets, inspection of individual bars, and collectors' reports. The individual tests are all diagrammed in this condensed report.

The report covers the facts of collection and tests and analysis thereof, resulting from 2036 samples of reinforcing bars rerolled from steel rails. Upon these samples 1719 tension tests and 1264 bend tests were made. The complete account of samples collected and tests made is listed in Table I.

The investigation covered a period of time from September, 1912, to February, 1913.

The investigation was based upon instructions received from Mr. C. F. W. Rys, Metallurgical Engineer, Carnegie Steel Co., Pittsburgh, Pa., Chairman of Sub-Committee V, on Steel Reinforcing Bars, of Committee A-1. The collection of samples was made and the tests were performed by the writer, or under his direction by the following persons: H. H. Scofield, Assistant Professor in the Laboratory for Testing Materials, Purdue University; G. E. Lommel, Instructor in Civil Engineering, Purdue University, as draftsman; and C. Kolb, Assistant Engineer of Tests, with several laboratory assistants.

Acknowledgment.—Acknowledgment is due to President W. E. Stone of Purdue University for providing full facilities for

TABLE I.—ACCOUNT OF SAMPLES COLLECTED DECEMBER 12, 1912.

Size of Bar.	Kind of Bar.	Number Received.	Mill.	Location in Rail.	Number of Tests made.	
					Tension.	Bend.
3/4-in.	Sq. Twist	32	A	Head	32	32
7/8 "	"	100	"	"	100	100
1 "	"	50	"	"	50	50
1/2 "	Sq. Twist	100	B	Head	100	100
1/2 "	Pl. Square	60	"	Billet	60	0
1 "	"	20	"	"	20	0
9/16 "	Cor. Round	71	"	Head	71	71
9/16 "	"	70	"	Flange	70	70
5/8 "	"	50	"	"	50	50
Special shipment of material rolled from new rails:						
3/8 "	Pl. Round	287	B	Web	60	0
7/8 "	"	120	"	Head	60	0
Successive Passes		60	"	Web	120	0
" "		60	"	Head	120	0
1/4-in.	Pl. Round	20	C	Head Reheated	20	20
1/4 "	Pl. Square	20	"	"	20	20
1/4 "	Sq. Twist	20	"	"	20	20
3/8 "	Pl. Round	20	"	"	20	20
1/2 "	Sq. Twist	70	"	Web	70	70
9/16 "	Pl. Round	20	"	"	20	20
5/8 "	"	20	"	Flange	20	20
5/8 "	Sq. Twist	70	"	"	70	70
3/4 "	Pl. Round	20	"	"	20	20
3/4 "	Sq. Twist	20	"	Head	20	20
7/8 "	"	10	"	"	10	10
7/8 "	Pl. Round	10	"	"	10	10
1 "	"	20	"	"	20	20
1 "	Sq. Twist	40	"	"	40	40
1 1/8 "	"	20	"	"	20	20
1 1/4 "	"	30	"	"	30	20
5/8 "	Pl. Square	140	D	Head	140	140
3/8 "	Pl. Round	113	E	Web	63	63
5/8 "	Cor. Square	109	"	Flange	59	59
7/8 "	"	110	"	Head	60	60
Total		2036			1719	1264

the testing work in the Materials Testing Laboratory of Purdue University. Special mention should also be made of the cordial support and free, open-minded cooperation of the Rail Steel Bar Manufacturers' Association, represented by Mr. E. E. Hughes, President, and Mr. A. S. Hook, Secretary, and to the officers and superintendents of the following companies: Laclede Steel Co., St. Louis, Mo.; Buffalo Steel Co., Tonawanda, N. Y.; Franklin Steel Co., Franklin, Pa.; Inland Steel Co., Chicago Heights, Ill.; Calumet Steel Co., Chicago Heights, Ill.; and Interstate Steel Co., Cambridge, O.

The thanks of the writer are also expressed to Robert W. Hunt & Co. for the donation of the services of an inspector during a portion of the investigation.

Acknowledgment is also thankfully made to Mr. P. E. Carhart, Inspecting Engineer of the Illinois Steel Co., for supplying a number of new rails for special investigation.

Instructions.—The general instructions under which the writer proceeded are contained in a letter from Mr. C. F. W. Rys, under date of August 6, 1912, as follows:

"Sub-Committee V, on Steel Reinforcing Bars, of Committee A-1 of the American Society for Testing Materials, desires to have you make an investigation to obtain data upon which to base a reasonable specification for rerolled reinforcement bars, so-called; that is, bars rerolled from rails or similar material.

"The investigation is to embrace the methods necessary to obtain representative samples for testing and the proper representative tests for material of this character. It should cover:

1. The quantity deemed proper for a lot for testing.
2. The effect of the size of the bar on the physical properties.
3. The effect of the design of the bar.
4. Variation in the properties of bars rolled from the head, web or flange of standard rails.
5. Variation in the properties of bars rolled from other material."

Limitations of Report.—This report covers reinforcing bars rerolled from steel rails, and does not present facts with reference to other reinforcing bars rolled from billet steel or miscellaneous material. Several matters of technical and scientific interest, which are not necessary to the formation of a specification, are postponed—as, for instance, the true elastic limit versus the yield point of twisted and plain bars. Chemical

analyses were not considered to be essential or helpful, and were omitted.

PROCESS OF MANUFACTURE: REROLLING RAILS FOR REINFORCING BARS.

The raw material used in the industry consists mainly of old rails which have been removed from service, although new rails known as seconds are used to some extent. These seconds are rails which have been rejected on account of some surface physical defects. Defects in an old or new rail which might interfere with the rolling, such as split heads, burrs or cracks, are carefully removed before the rail is permitted to enter the furnace. The old rails are, of course, mainly Bessemer. The kind of rails entering the furnace, and the samples collected and reported upon in this investigation are noted in the collectors' reports.

The rails used are usually broken into lengths of 10 to 15 ft. before heating, although at least one mill is equipped to roll rails in their full length of 33 ft. The sizes and lengths of rails used depends in a great measure on the sizes of bars to be rolled. To roll bars of large cross-section and of considerable length requires a rail with a large head which is but slightly worn. When it is desired to roll a small bar from the web a shorter rail must be used, as otherwise the resulting bar would not only be inconvenient to handle, but too long for the hot beds.

The furnaces are equipped to hold from 45 to 65 rails, side by side in a horizontal position. The rails are fed to the furnace by a conveyor, and enter sidewise in some plants, and endwise in others. The rate of progress of the rail through the furnace is dependent on the speed of rolling. The distance from the coolest to the hottest portion of the furnace is such that the rail is heated slowly and uniformly. The average rate of rolling of ordinary bars is from $\frac{3}{4}$ to $1\frac{1}{4}$ minutes each. Assuming a capacity of furnace of 60 rails, the time in the furnace would be from 45 to 75 minutes, as the case may be. The fuel used is coal, producer gas, or oil, and since all furnaces are equipped with forced draft the temperature is easily and uniformly regulated.

The rolling is very similar to that of any bar or small-shape mill, except in one particular. The head, web and flange must be rolled separately; consequently the first or first two passes

must strip these elements from each other. The different parts are then rolled into the desired sizes and shapes, as in an ordinary mill. The size of mill, number of passes and reduction at the

TABLE II.—NUMBER OF TESTS PER TON OF OUTPUT DECEMBER 12, 1912.

Size and Kind of Bar.	Mill.	Total Number of Tests.	Number of Tests in Gage Length.	Tons Output.	Tests per Ton.	
					In Gage.	Total.
¾-in. Sq. Twist	A	32	27	. ...	...	...
⅞ " "	"	100	53	17.5	3.0	6.0
1 " "	"	50	28	11.0	2.5	5.0
½ " Sq. Twist	B	100	95	20.0	5.0	5.0
9/16 " Cor. Round	"	71	69	13.12	5.0	5.0
9/16 " "	"	70	70	11.25	6.0	6.0
⅝ " "	"	50	48	6.0	8.0	8.0
Reheated. ¼-in. Pl. Round	C	20	19	.....	...	...
Reheated. ¼ " Pl. Square	"	20	18	.....	...	...
Reheated. ¼ " Sq. Twist	"	20	19	.....	...	...
Reheated. ⅜ " Pl. Round	"	20	20	.....	...	...
½-in. Sq. Twist	"	70	64	.....	...	...
9/16 " Pl. Round	"	20	19	.....	...	...
⅝ " "	"	20	20	.....	...	...
¾ " Sq. Twist	"	70	55	.....	...	...
¾ " Pl. Round	"	20	20	.....	...	...
¾ " Sq. Twist	"	20	18	.....	...	...
⅞ " "	"	10	7	.....	...	...
⅞ " Pl. Round	"	10	10	.....	...	...
1 " "	"	20	20	.....	...	...
1 " Sq. Twist	"	40	20	.....	...	...
1⅛ " "	"	20	7	.....	...	...
1¼ " "	"	30	18	.....	...	...
⅝ " Pl. Square	D	140	132	21.0	6.0	7.0
⅜ " Pl. Round	E	63	62	9.94	6.0	6.0
⅝ " Cor. Square	"	59	57	19.36	3.0	3.0
⅞ " "	"	60	57	23.03	2.5	2.6

various passes is dependent upon the size and shape of the bar to be rolled. However, it is necessary that the larger sizes be rolled from the head and that the smaller sizes be rolled from the web or flange which has the smallest original section.

There is a discard from the end of the bar, and the portion of the bar representing the part of the web containing the bolt holes is sheared off either during the process of rolling or after the bar is rolled.

The changes in tensile strength and elongation consequent upon the reduction of the rail in the rolls have been determined in this investigation. (See Tables VIII, IX and X, and Figs. 29 and 30, Plate VI.)

The heat treatment in the furnace, the temperature of rolling and the temperature changes in the bar during twisting are all subject to well-known scientific laws, and need the same careful regulation as steel of like carbon content.

Although reinforcing steel is rolled from all three parts of the rail, most of it comes from the head. The web and flange furnish the small shapes such as flats, channels, angles and tees. These are furnished very extensively to the furniture and agricultural implement industry. The latter industry also receives the major portion of harrow teeth and other small parts from plain bars of rerolled rail steel. One company is making built-up high-tension electric transmission-line poles from U-bars and flats of rerolled rail steel. Brake beams are also manufactured.

SELECTION OF SAMPLES.

At the outset of the investigation it was evident that a method of sampling must be planned so as to forestall the criticism that the samples might represent better material than the normal product of the mills. To this end the rolling schedules of several mills were determined a week or two in advance, and the collection made at unexpected times. These schedules were necessary so that it might be certain that the mills would be rolling reinforcing bars, and not some other product.

In the opinion of the writer and his collectors the rails fed to the furnaces were not specially selected and could not be.

The samples resulted from the rerolling of rails of various size and manufacture. The lighter sections were originally rolled about 1885 on the average; while the larger sections were of later rolling, about 1900 or thereafter.

The endeavor was to take such samples, spaced at equal intervals, that the results of tests would represent normal work-

ing conditions. Five out of the six mills concerned were sampled at various periods from September to December, and all kinds and sizes of bars from the various parts of the rail were represented in the samples.

The design of the deformed bar rerolled from rails is shown in Fig. 1.

Of course, the results are based upon a wide range of working conditions with respect to temperature of the air, design

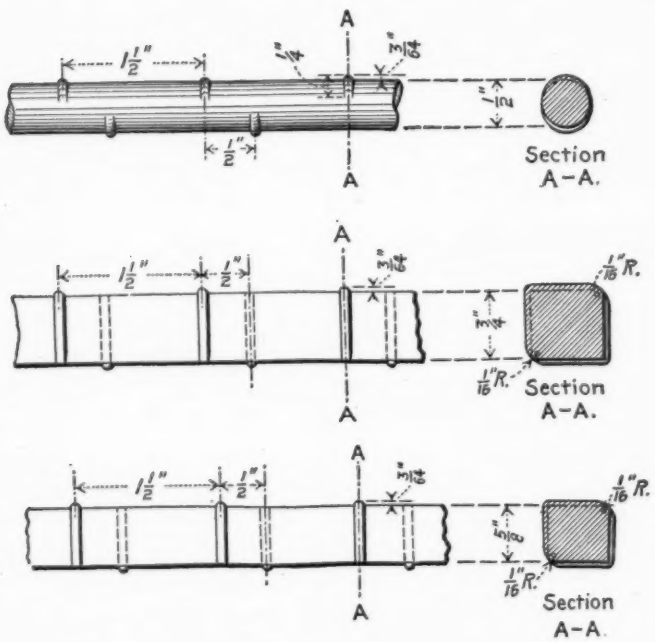


FIG. 1.—Design of Deformed Bar Rerolled from Rails.

and size of bar, chemical composition, and size of the rails entering the mills. It is felt that under these conditions the data of tests may be sufficiently extensive to allow the formation of a specification, which shall be applicable to the normal product. The diagrams showing the effect of several factors, such as size of bar, design of bar, origin of bar, are of course expressions of tendencies rather than exact relations. To isolate any one factor would require the operation of the mill

especially for the tests, and this would destroy the representative value of the tests, to secure which value was the main aim of the investigation.

In contrast to this method, the selection of samples from material delivered to buildings under construction would be more or less haphazard. Records of mill tests made by other persons have been consulted to determine the relation of the usual commercial inspection tests to the tests made for this report.

The plan of sampling was briefly as follows: The collector stood at the shears at the end of the hot beds, and took a piece 3 ft. long off the fore end of ten consecutive bars representing ten consecutive part-rails (not a 30-ft. rail, but the portion of the rail that was put in the furnace). Forty part-rails were allowed to pass without sampling, and then ten others were sampled in like manner. This process was repeated for a period of from one to two days for each mill. In some instances samples were collected that would have been rejected by the inspector before they would have been loaded on the cars. These are noted on the diagrams.

By referring to Table II will be seen that the number of tension-test bars per ton of output varied from 8 to 2.6.

In addition to this normal sampling of old rails, a special investigation was made to determine the changes in the mechanical quality of the steel during the successive passes through the rolls. For this purpose new Bessemer rails of 60 and 75-lb. section were secured, and samples taken at the various passes, including the finished bar. Samples were also cut from the original rails. The special investigation is covered in Tables VIII, IX and X (Plate VI), and XI.

In the case of mill C certain samples were taken representing small bars that were rolled from reheated pieces of larger bars of rerolled material. These are marked "R." (See Fig. 21.)

METHOD OF TESTING.

All bars were tested in the manufactured form, without surfacing.

Tension Tests.—The tension test was made under the usual conditions, with observations of the yield point (by the drop

TABLE III.—STRENGTH AND DUCTILITY OF TWISTED BARS AS AFFECTED BY LOCATION OF FRACTURE.

MILL "C" SHIPMENT.

Size and Kind of Bar.	Percentage Breaking in Gage Length.	Percentage Breaking Outside Gage Length.	Breaks in Gage Length.			Breaks in Middle Third.			Breaks not in Grips.			Breaks in Grips.			Percentage Failures in Bend Test.	Percentage Breaking in Grips.
			Tensile Strength, lb. per sq. in.	Elongation, per cent.	Reduction, per cent.	Tensile Strength, lb. per sq. in.	Elongation, per cent.	Reduction, per cent.	Tensile Strength, lb. per sq. in.	Elongation, per cent.	Reduction, per cent.	Tensile Strength, lb. per sq. in.	Elongation, per cent.	Reduction, per cent.		
¼-in. Sq. Tw.	95.0	5.0	88 050	11.8	42.4	80 210	12.2	44.2	82 200 (102.5)	6.5	40.4 (91.7)	.....	.....	.....	.....	.....
½ " "	91.4	4.3	95 780	15.8	36.9	94 070	16.8	33.8	98 670 (104.9)	9.5	32.0 (94.7)	92 580 (98.5)	12.8	27.2 (80.5)	8	4.3
⅝ " "	78.6	2.9	90 000	18.8	39.1	88 320	19.3	40.5	96 400 (109.0)	15.0	43.5 (107.2)	93 740 (106.1)	11.1	15.4 (38.0)	4	18.5
¾ " "	90.0	5.0	89 130	20.3	38.5	87 580	21.0	37.6	84 900 (96.9)	21.0	48.0 (127.8)	87 500 (100.0)	12.0	8.6 (22.8)	0	5.0
⅞ " "	70.0	0.0	101 400	14.0	26.5	103 470	12.8	45.3	.....	.....	.....	109 170 (105.5)	7.7	9.4 (20.8)	10	30.0
1 " "	50.0	5.0	95 980	16.0	25.3	94 810	16.6	26.9	99 850 (105.1)	10.3	13.9 (51.7)	92 370 (97.4)	6.9	9.3 (34.6)	18	45.0
1⅛ " "	35.0	5.0	99 730	17.3	21.5	98 450	18.3	25.7	99 100 (100.7)	11.0	14.2 (55.3)	101 650 (103.2)	8.2	9.3 (36.2)	20	60.0
1¼ " "	60.0	0.0	89 560	21.1	34.3	85 380	23.4	39.1	.....	.....	.....	92 430 (108.1)	9.3	10.9 (27.9)	.....	40.0

MILL "A" SHIPMENT.

¾-In. Sq. Tw.	84.4	3.1	95 920	19.2	37.5	95 370	19.6	40.1	109 300 (115.0)	4.0	6.8 (16.8)	87 890 (92.3)	12.6	14.2 (35.4)	6	12.5
⅞ " "	53.0	11.0	92 100	17.3	27.9	89 730	17.7	27.5	96 350 (107.2)	11.3	11.3 (41.2)	97 410 (108.3)	9.4	11.5 (41.9)	13	36.0
1 " "	56.0	2.0	91 250	15.8	26.5	88 400	18.2	29.4	96 300 (108.9)	14.0	14.0 (47.7)	95 360 (107.6)	6.5	9.6 (32.6)	28	42.0

NOTE.—The values in parentheses show the percentage ratio of Tensile Strength and Reduction for "Breaks not in Grips" and "Breaks in Grips" to these properties for "Breaks in Middle Third."

of beam), ultimate strength, elongation and reduction of area. The bars were inspected before test for surface defects, evidence of over-heating, etc. The speed of test was $\frac{3}{4}$ in. per minute on the 300,000-lb. machine and $\frac{1}{3}$ in. per minute on the 30,000-lb. machine.

Comments on Tension Tests.—The usual difficulty was found in producing fracture in the gage length in the case of twisted bars. The influences operating in this case were the crushing

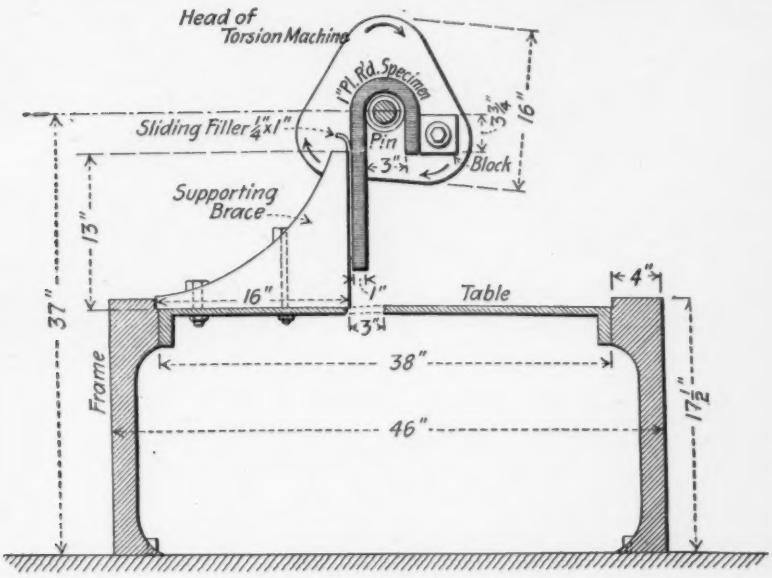


FIG. 2.— Bend Test Machine.

of the edges of the twisted bar by the grips and the possible torsion and bending due to eccentric gripping. This influence operated more to prejudice tests of large twisted bars than small twisted bars, and the breaks outside the grips were more frequent in the case of bars of high strength.

A special analysis is made in Table III of the location of the fracture and its influence on the results of tests.

Since a break outside of the gage length is a matter pertaining to the technic of testing rather than to the quality of

the manufactured article, the ordinary procedure was adopted: only those bars which broke inside the gage length were used to furnish data for this report. The number of bars breaking in gage length will be found in Table II.

It would have been possible to mold grips to fit the twisted bars if only one or two sizes of twisted bars had been collected. With the variety of sizes and variation of pitch represented in the samples, however, it was considered impracticable to supply such a collection of grips.

Bend Tests.—After one end of the 3-ft. bar had been pulled, the other end, which was unaffected by the tension test, was bent cold; that is, at the temperature of the laboratory (70° F.). The machine used was the twisting head of a Riehlè 200,000-in-lb. torsion machine which supplied a steady twisting moment. The diameter of pin used was that specified in the proposed Standard Specifications for Rail-Steel Concrete Reinforcement Bars presented for adoption at this annual meeting of the Society, as follows: For high-grade plain bars, three times the thickness; for deformed bars, four times the thickness.

For the purpose of this investigation, twisted bars were classed as deformed and tested as manufactured.

The method of making the bend test is illustrated in Fig. 2. Provision was made for the creeping of the end of the bar. The final bend procured was the full angle recorded. It was of course necessary to bend the bar to a somewhat greater angle, so that the recorded angle would be the net angle after the spring had disappeared from the bar.

MECHANICAL NATURE OF MATERIAL.

The results of tests appended to this report are shown in detailed diagrams, general diagrams and tables. Individual tests are shown in Figs. 3 to 14, Plates I and II, and Figs. 15 to 20, Plates III and IV.

General results are given in Table IV and Fig. 21.

Tension Tests.—A comparison of this rerolled steel of various design with other grades of steel is most readily made by plotting a strength-elongation curve as used by Tetmajer.



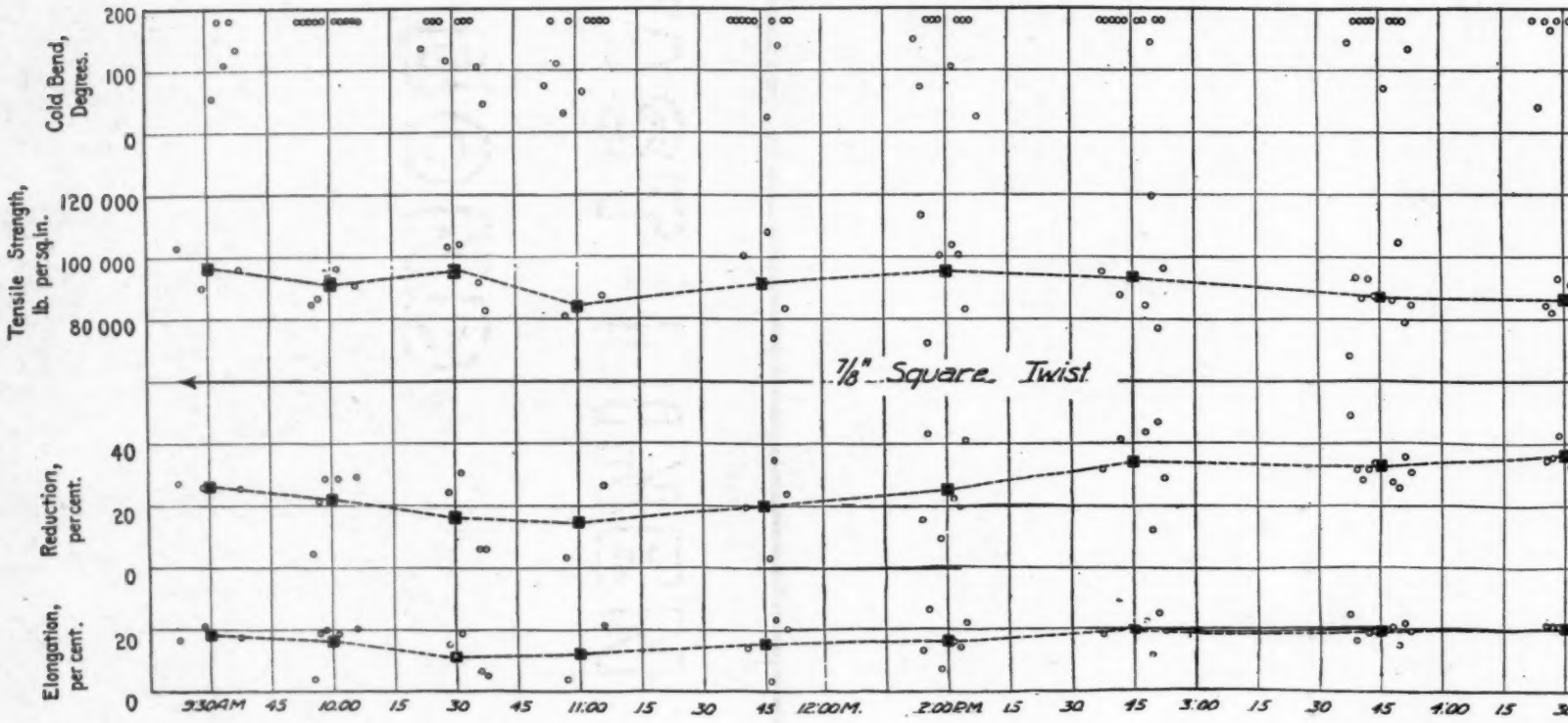
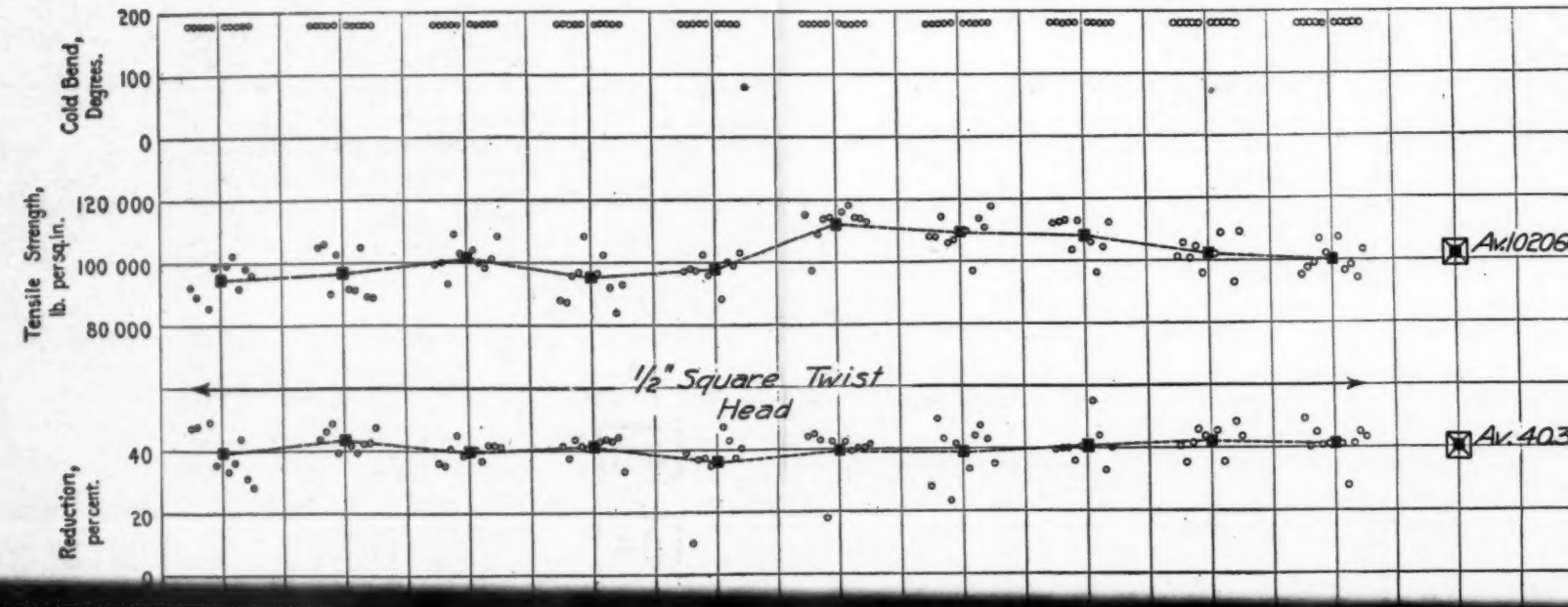
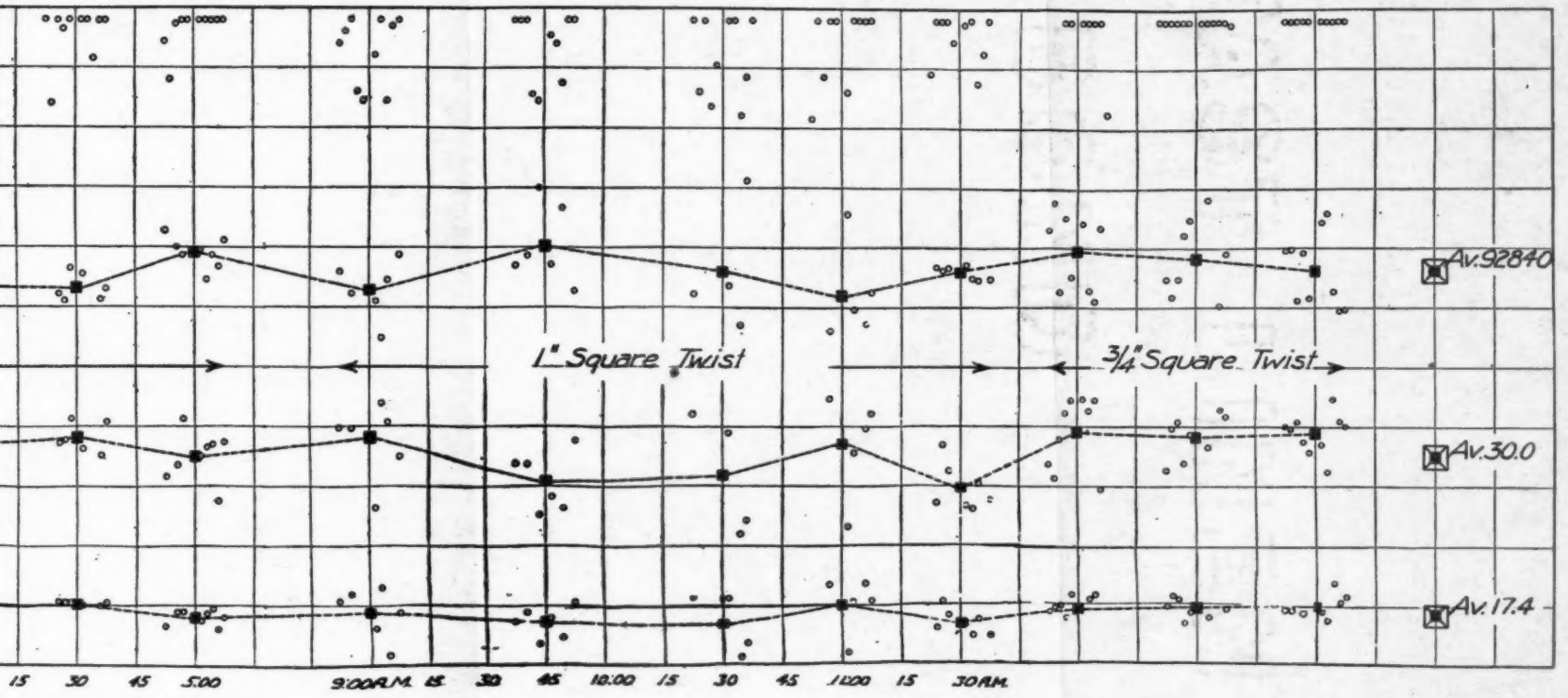
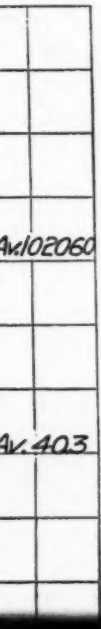


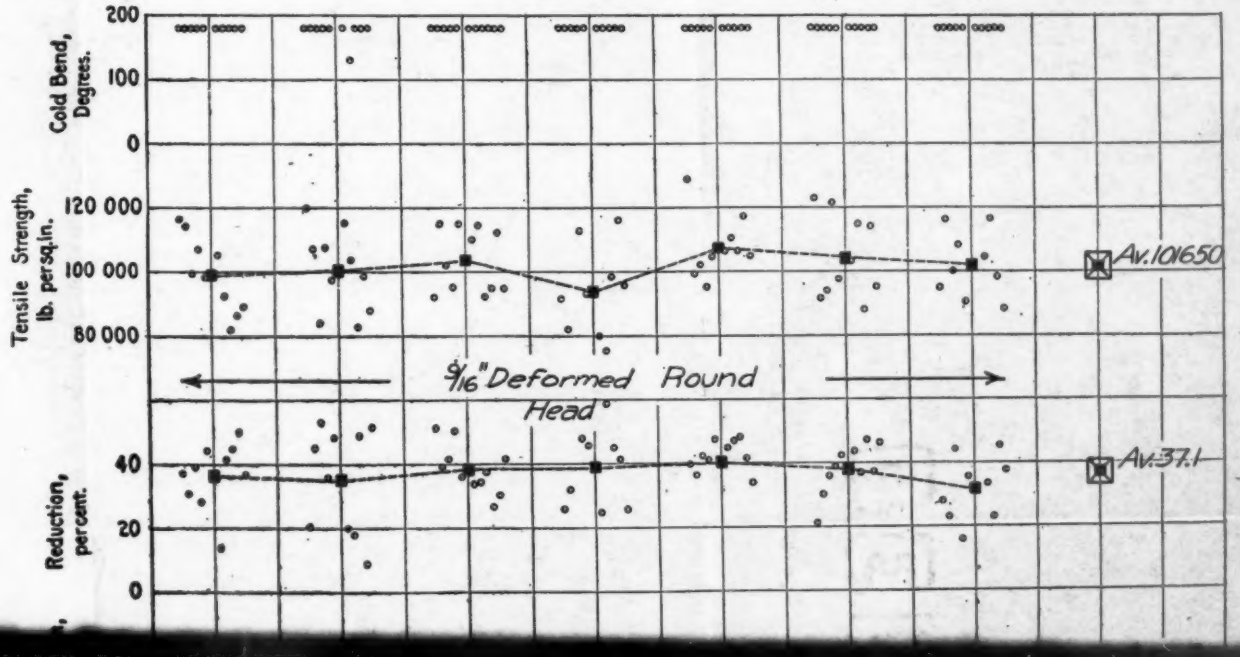
FIG. 3.—Tests on Shipm





on Shipment No. 1, Mill "A."





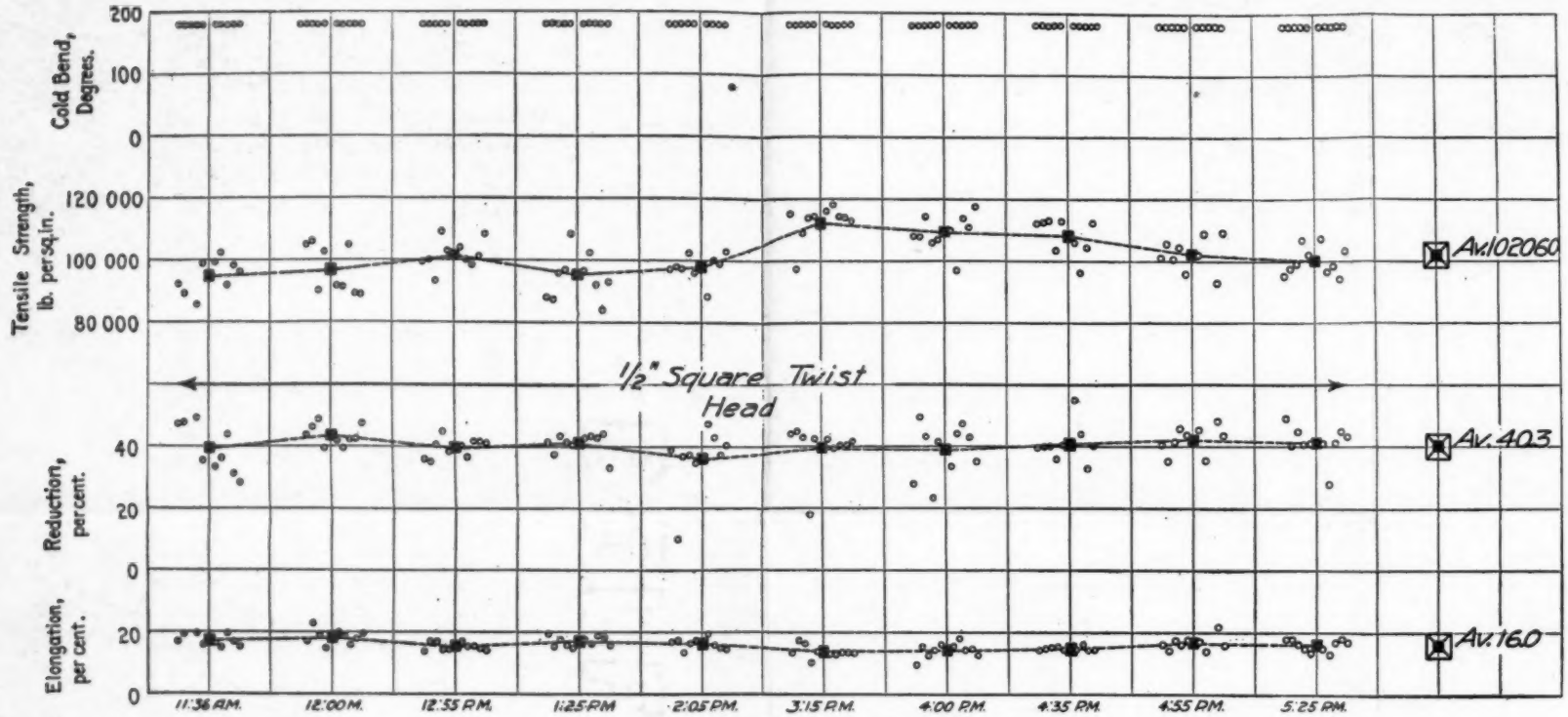


FIG. 4.—Tests on Shipment No. 1, Mill "B."

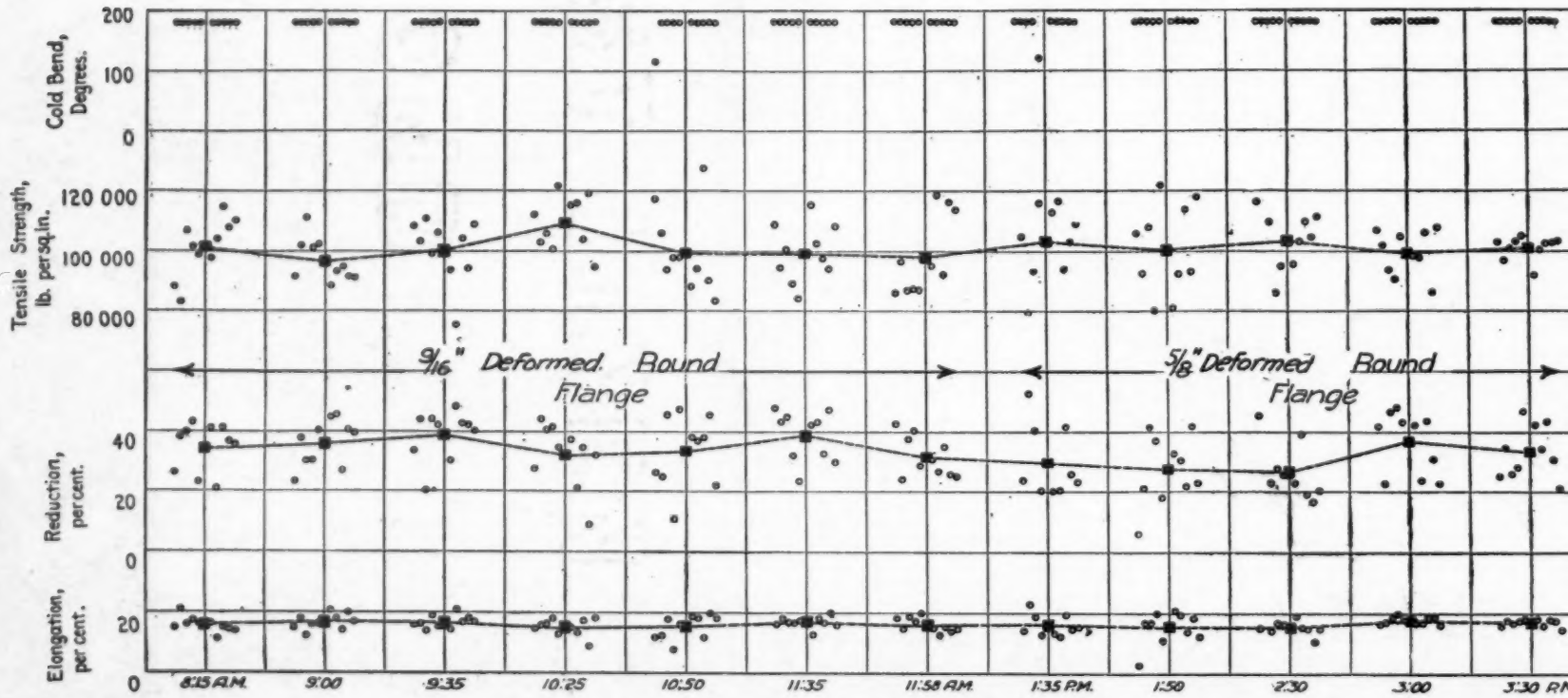


FIG. 6.—Tests on Shipment No. 2, Mill "B."



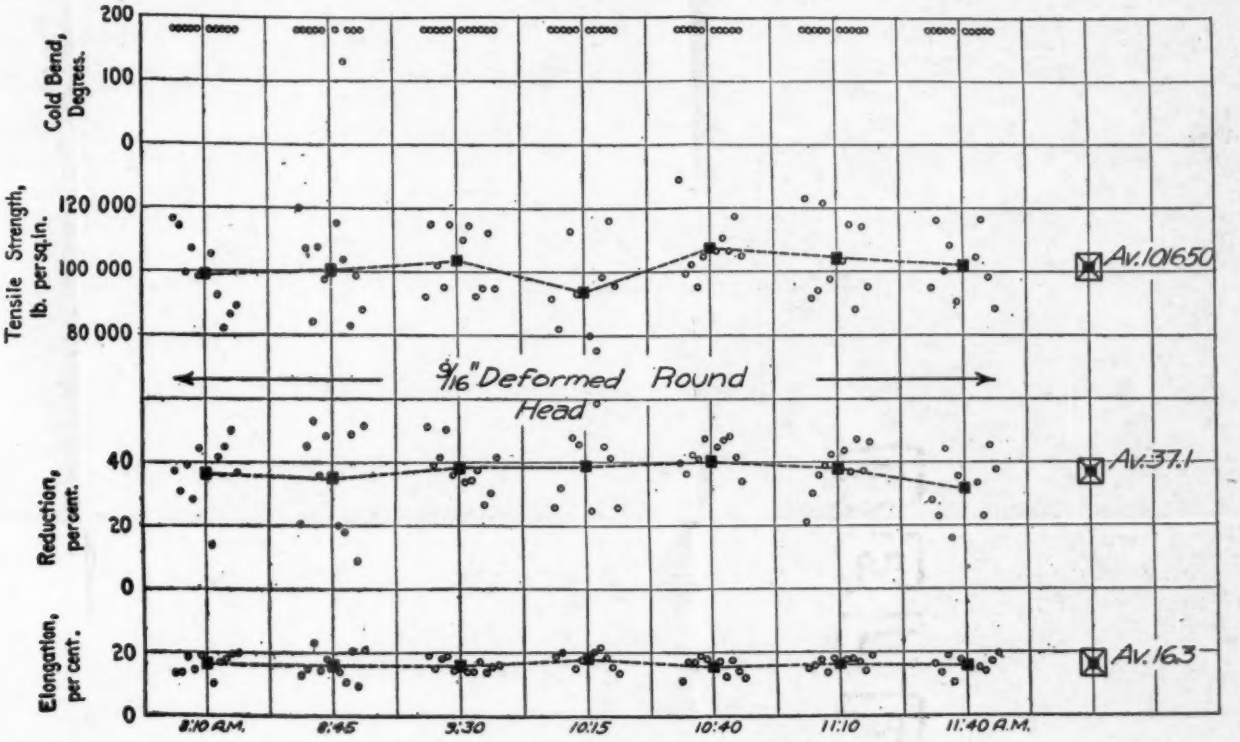
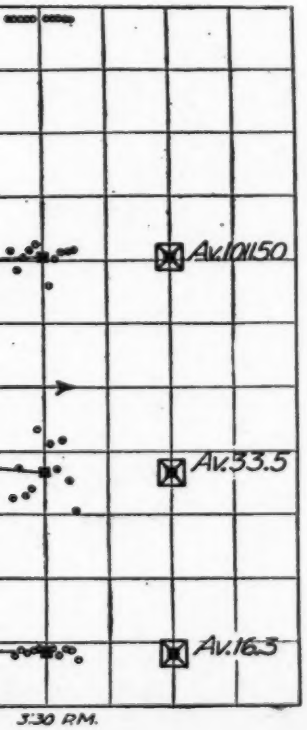


FIG. 5.—Tests on Shipment No. 2, Mill "B."



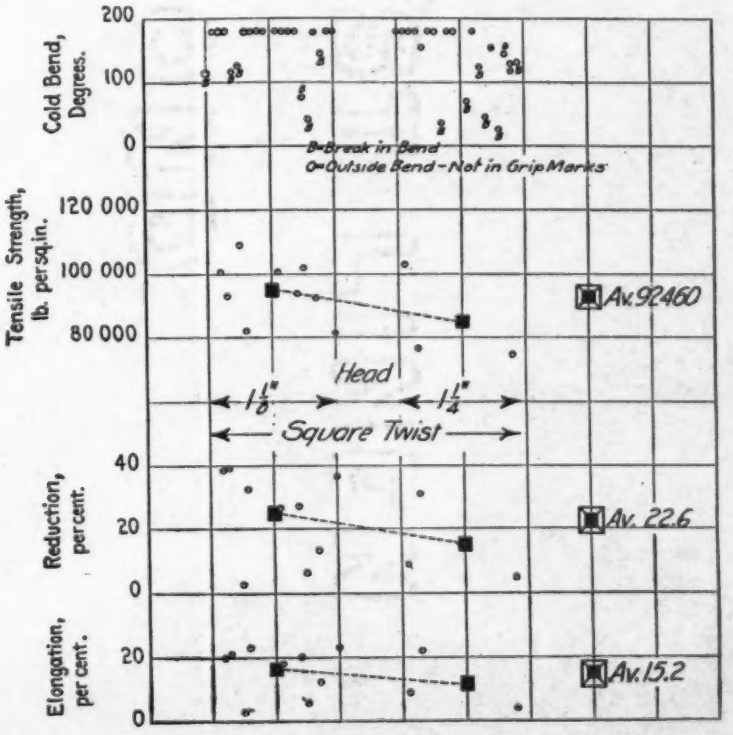


FIG. 7.—Tests on Shipment No. 4, Mill "B."

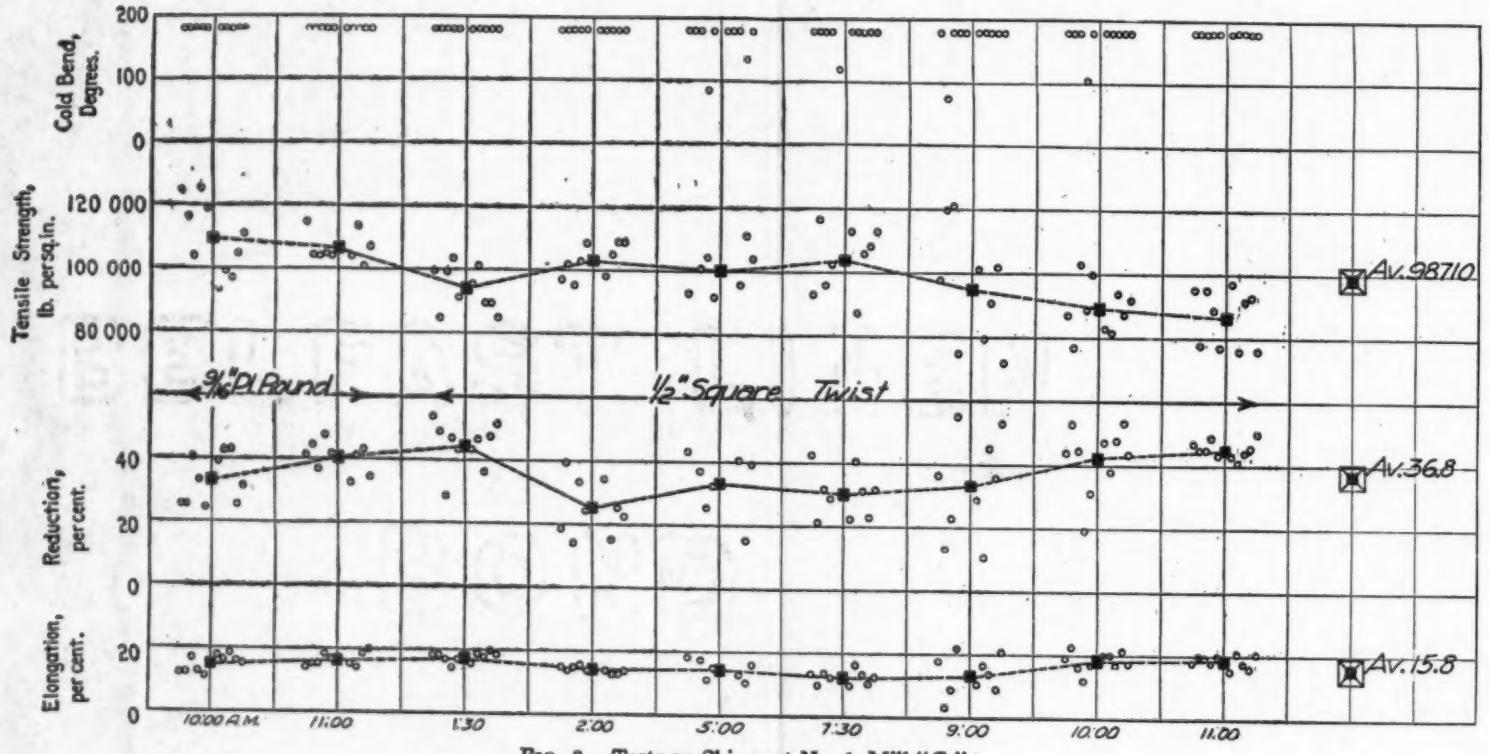
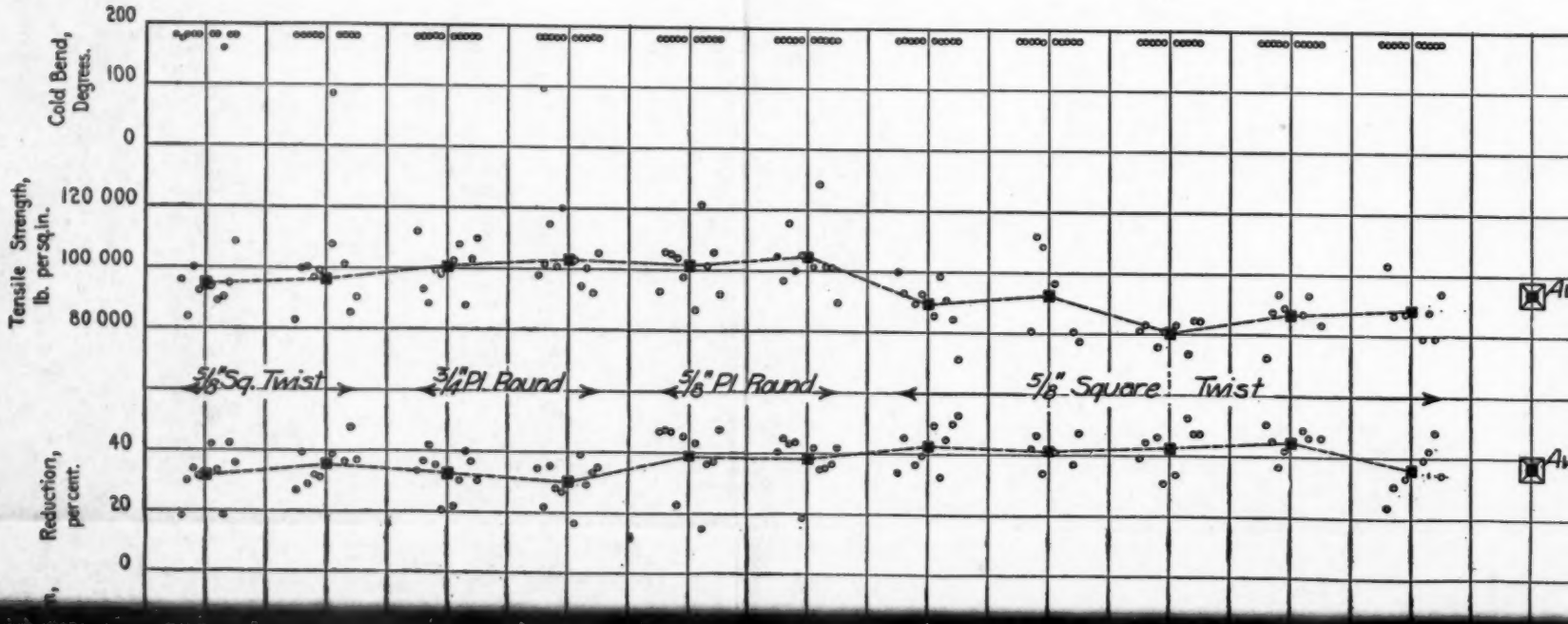


FIG. 8.—Tests on Shipmeat No. 1, Mill "C."



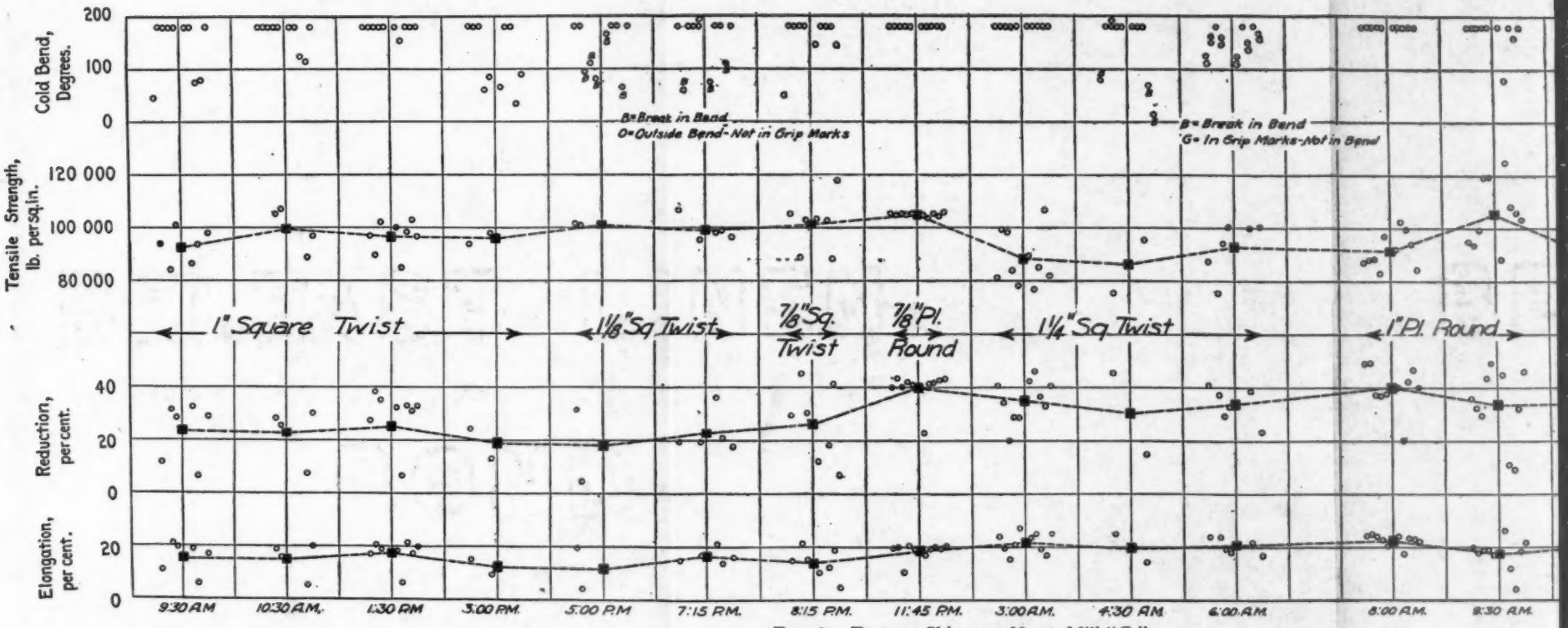
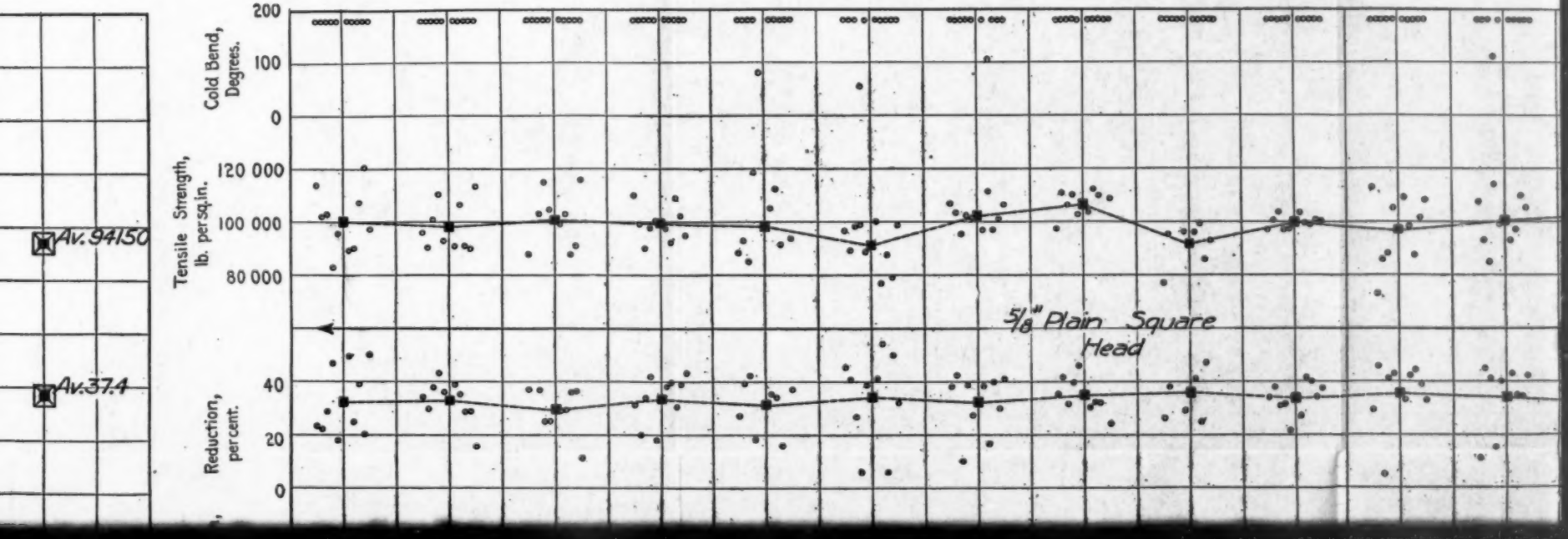
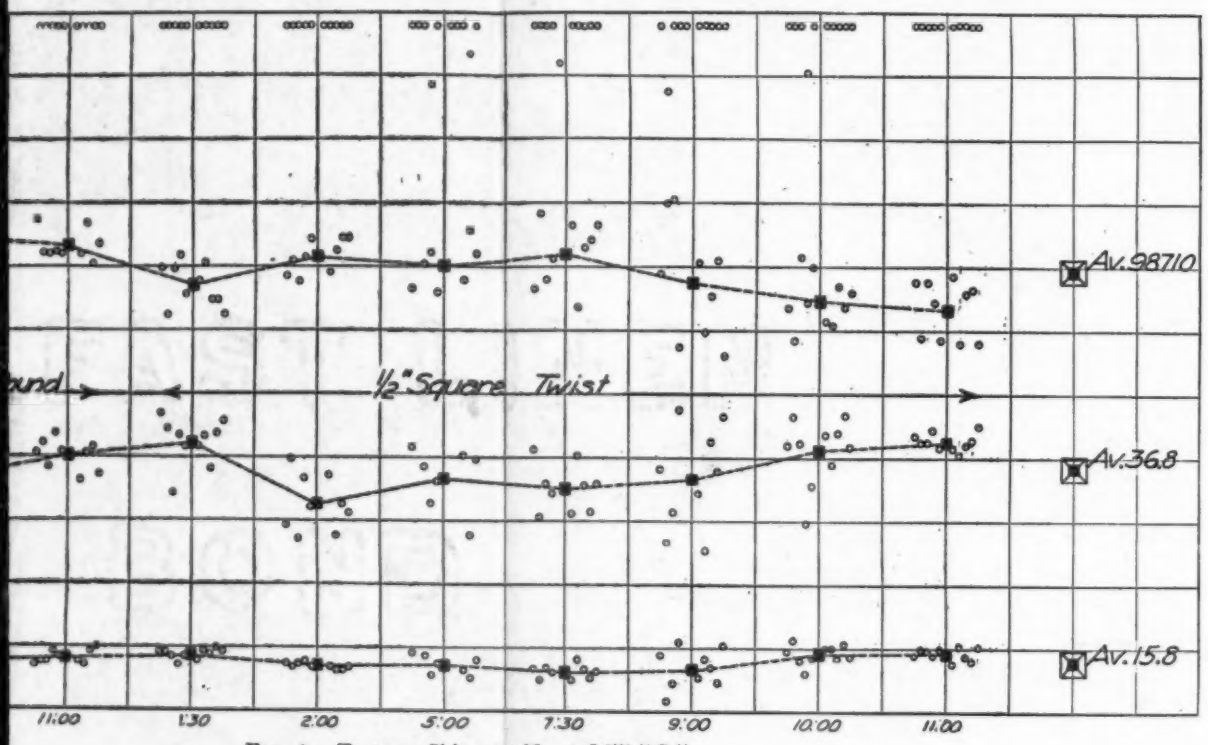


FIG. 9.—Tests on Shipment No. 1, Mill "C."





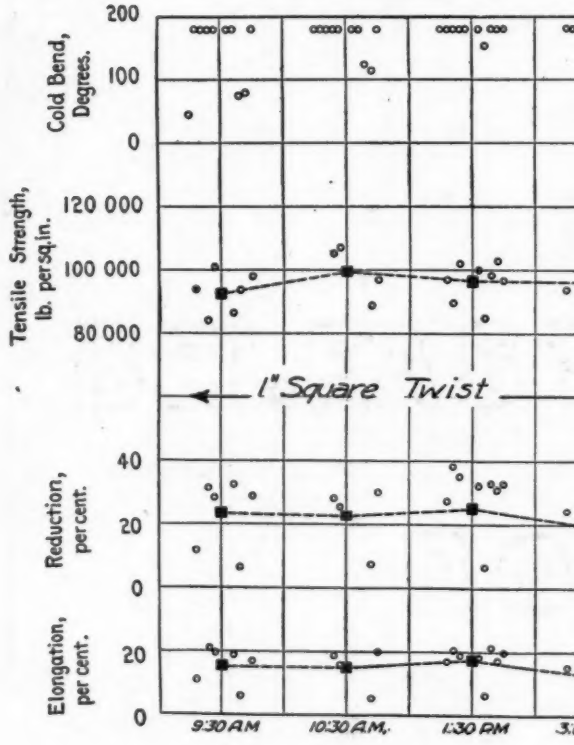
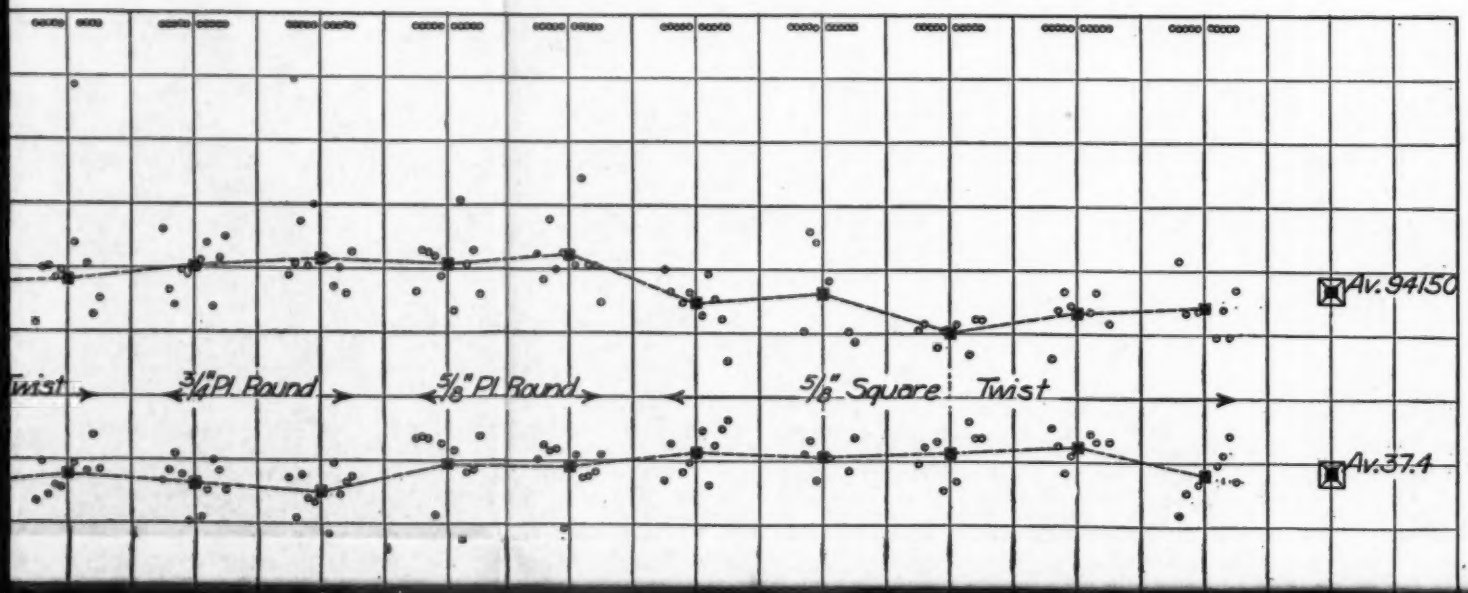
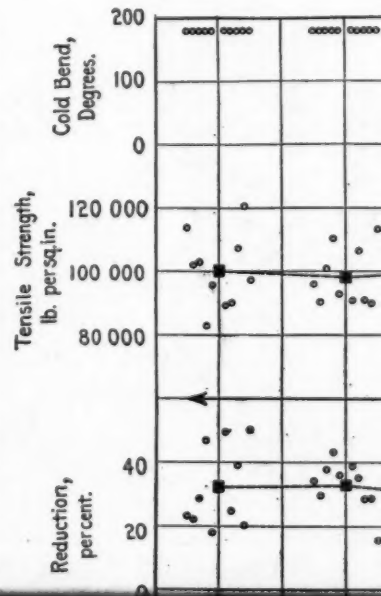


FIG. 8.—Tests on Shipment No. 1, Mill "C."





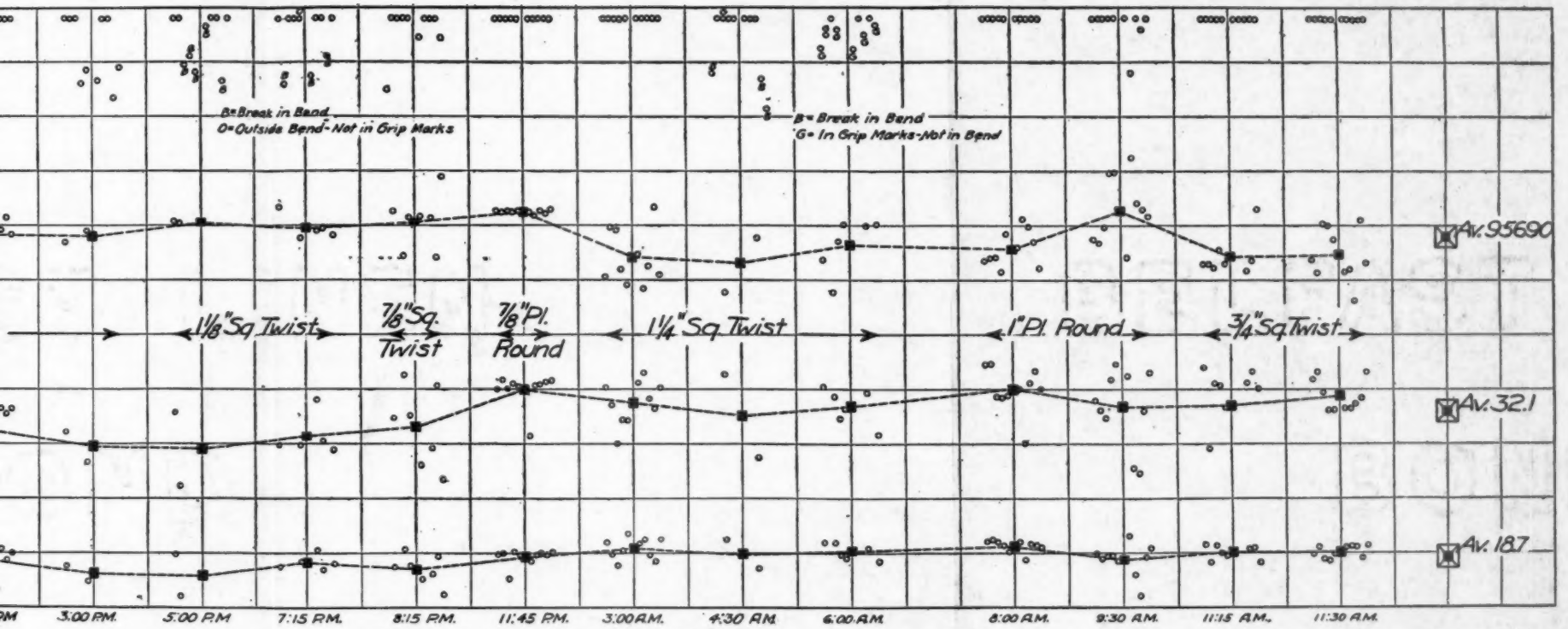
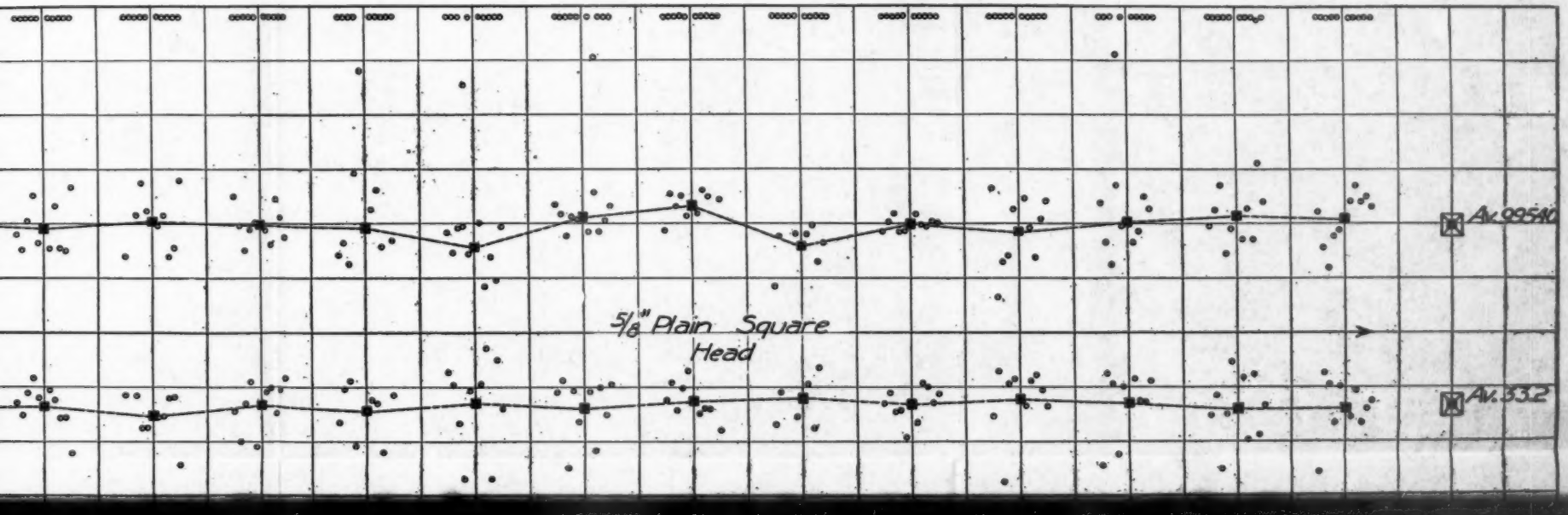


FIG. 9.—Tests on Shipment No. 1, Mill "C."



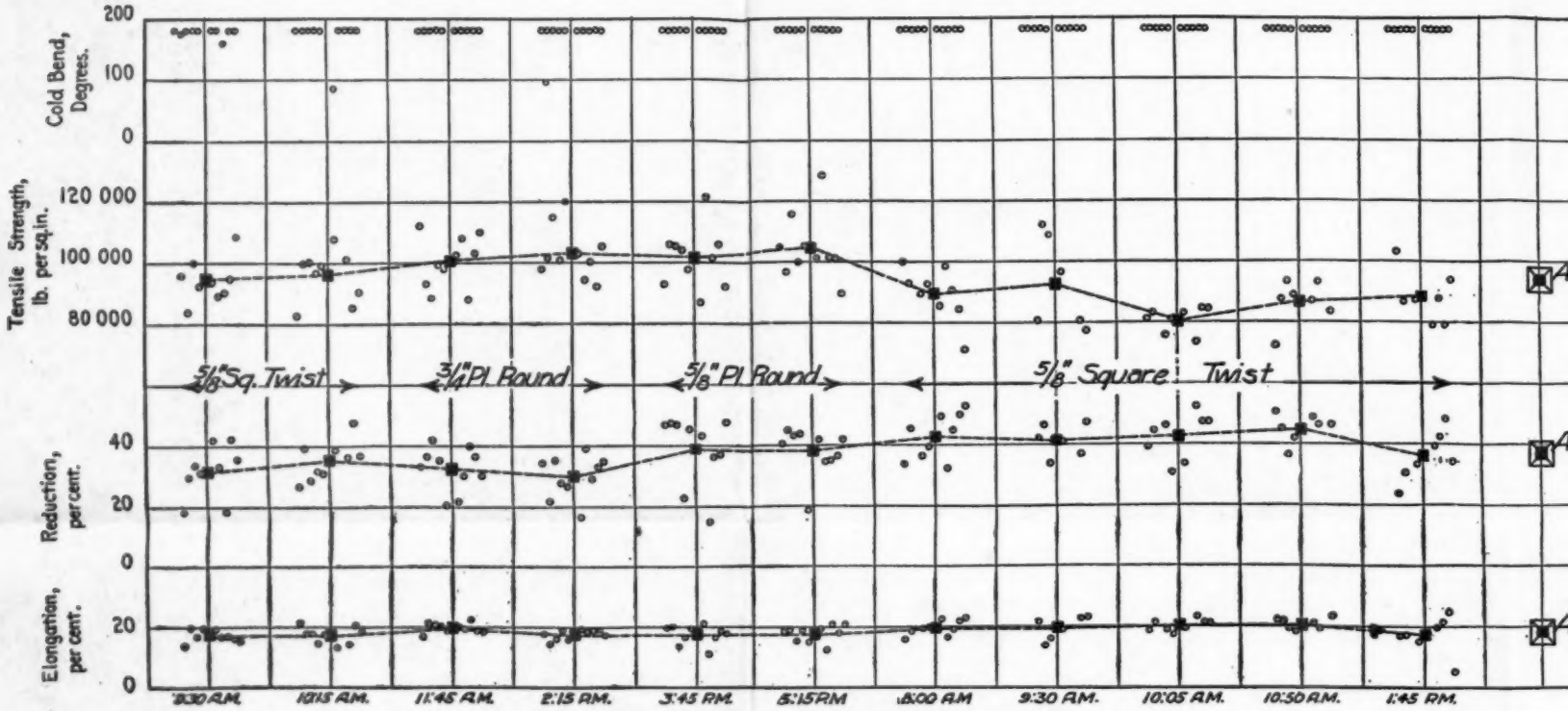


FIG. 10.—Tests on Shipment No. 1, Mill "C."

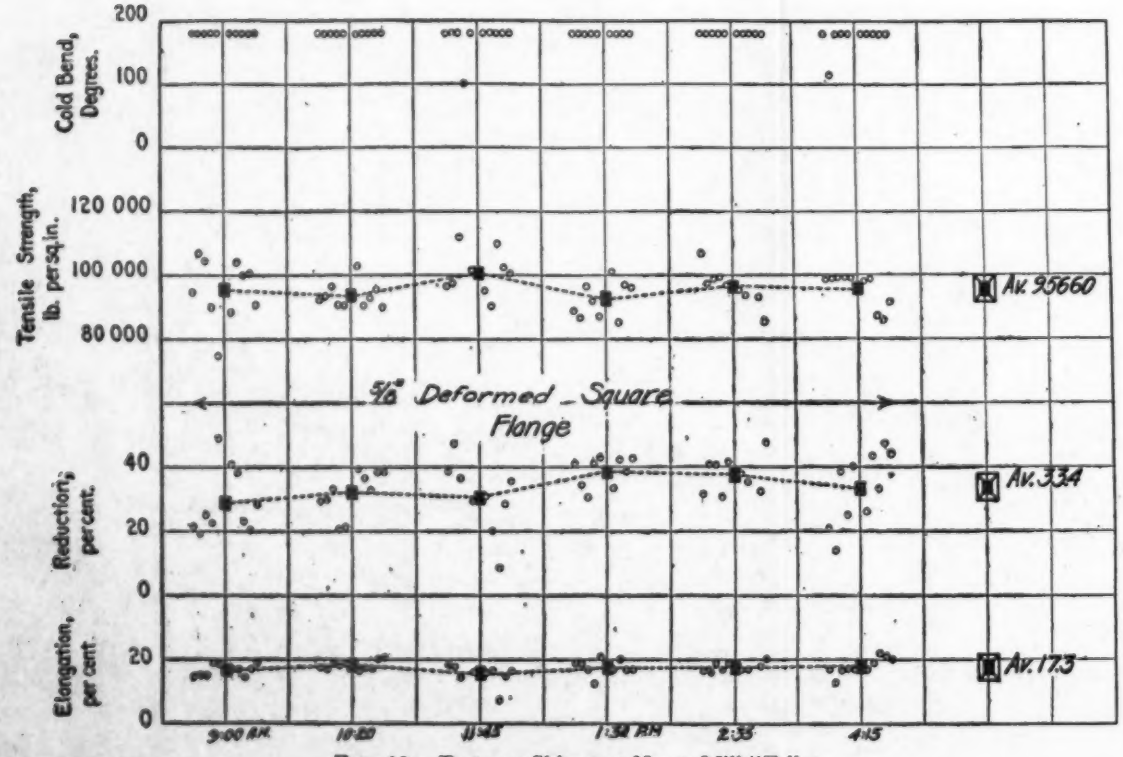
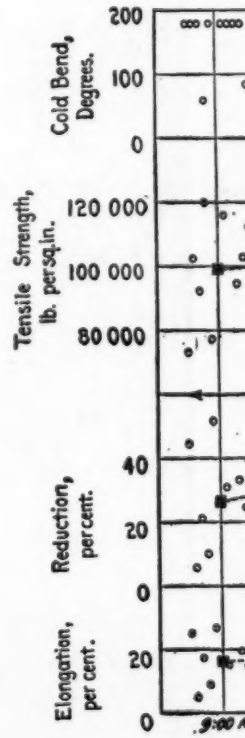


FIG. 12.—Tests on Shipment No. 1, Mill "E."



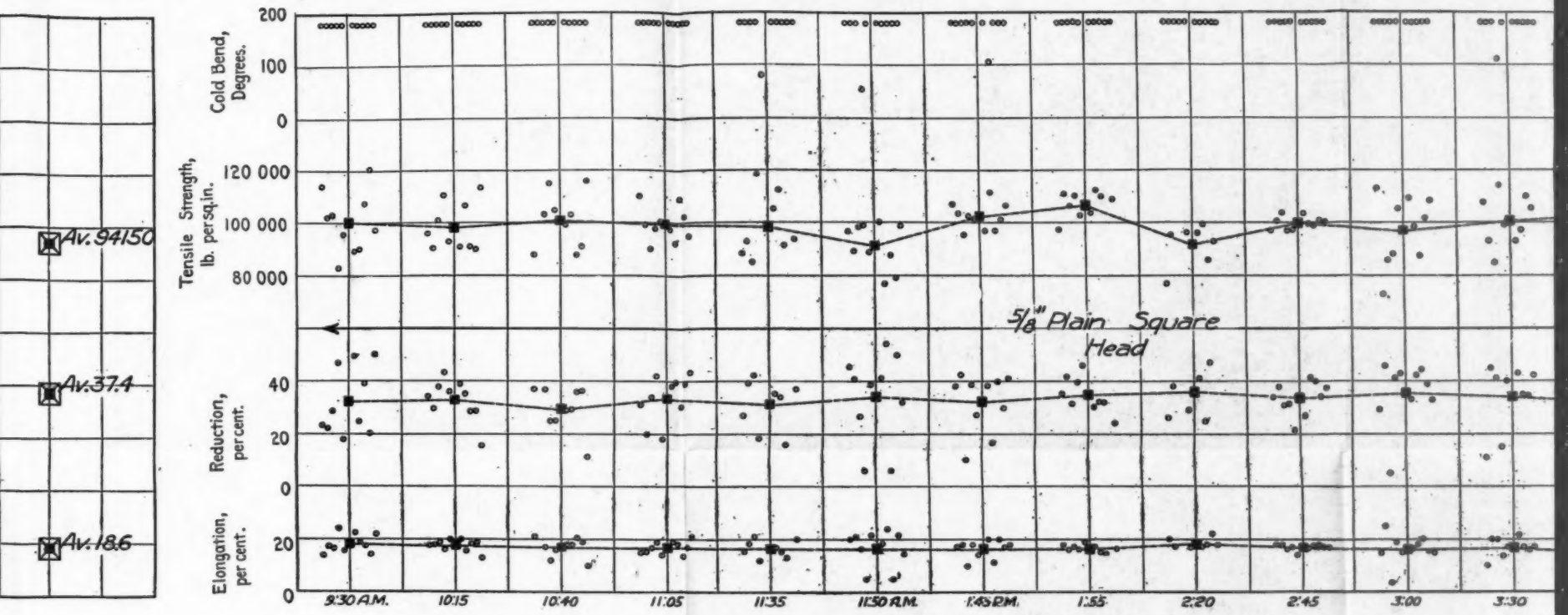


FIG. 11.—Tests on Shipment No. 1, Mill "D."

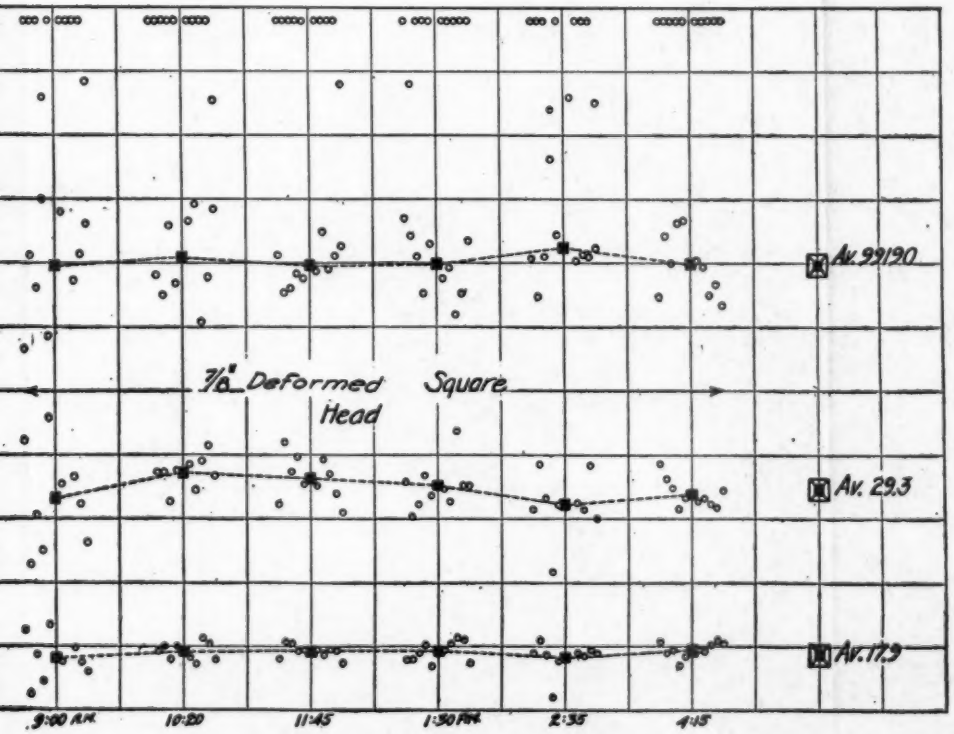


FIG. 13.—Tests on Shipment No. 1, Mill "E."

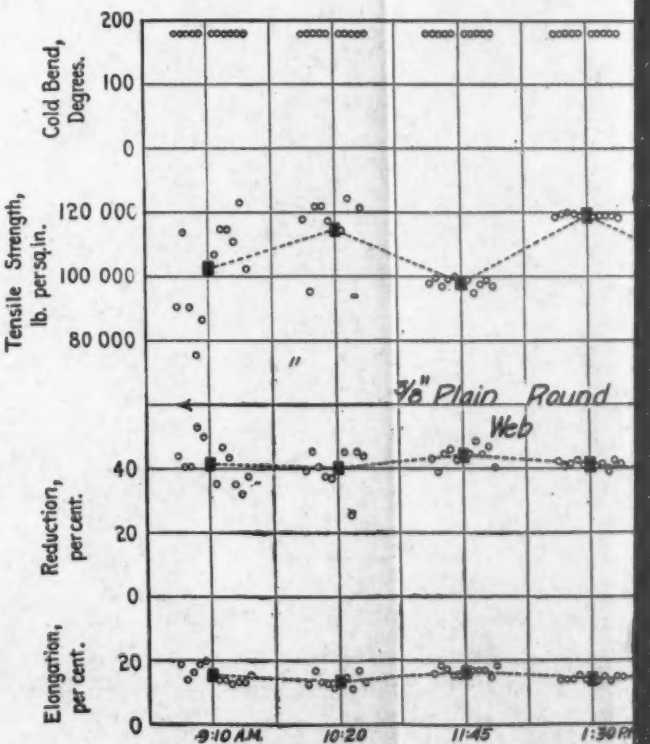
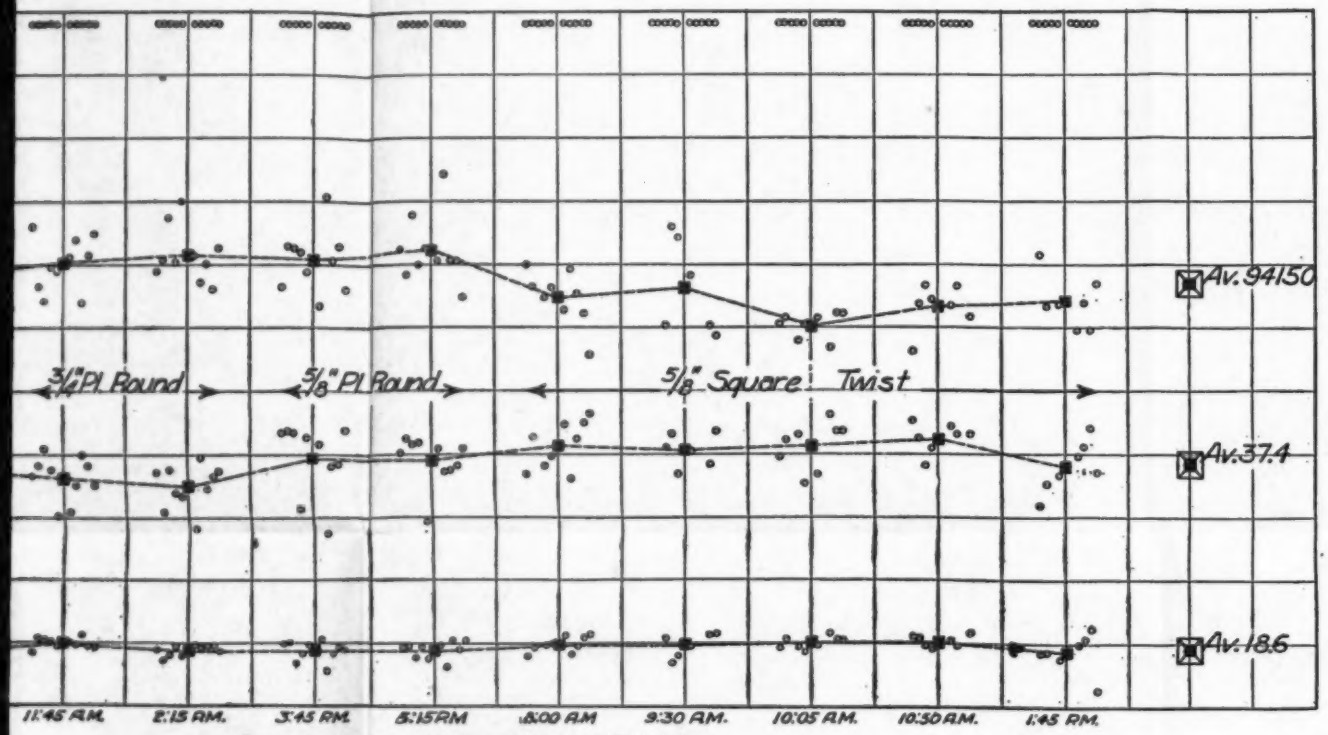


FIG. 14.—Tests on Shipment N

FIG. 8.—Tests on Shipment No. 1, Mill "C."



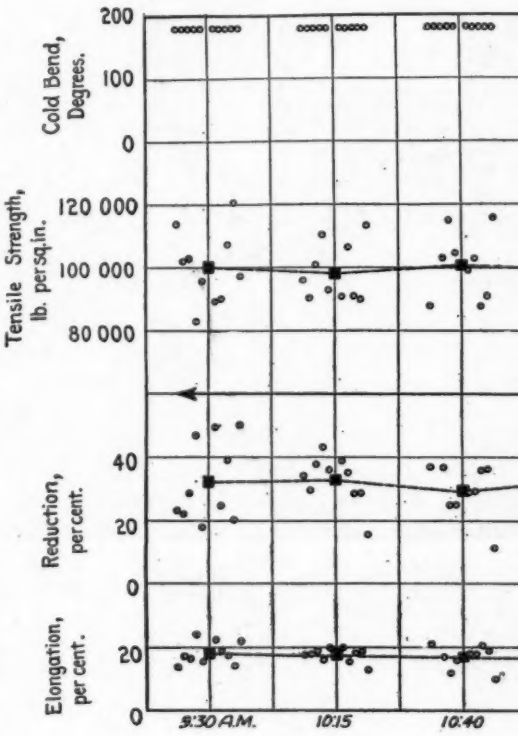
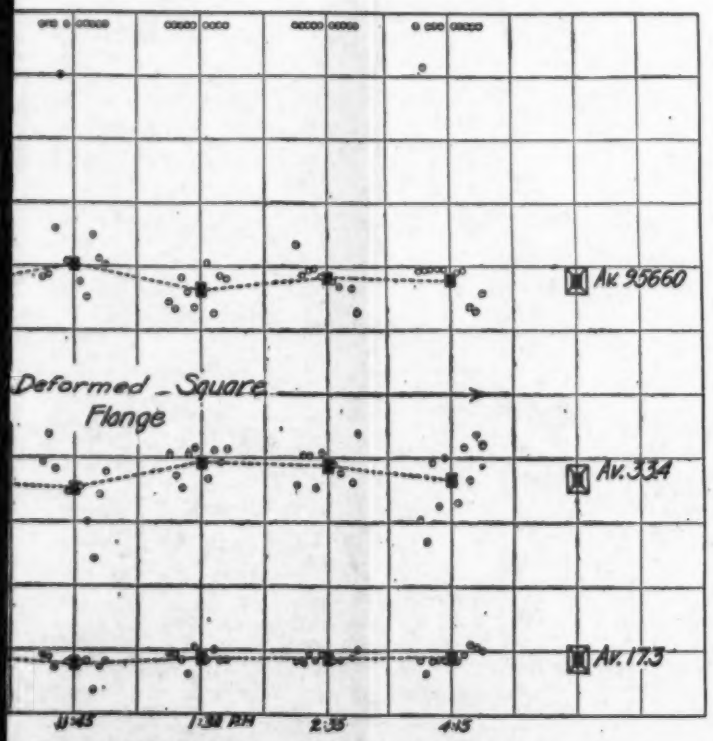


FIG. 10.—Tests on Shipment No. 1, Mill "C."



—Tests on Shipment No. 1, Mill "E."

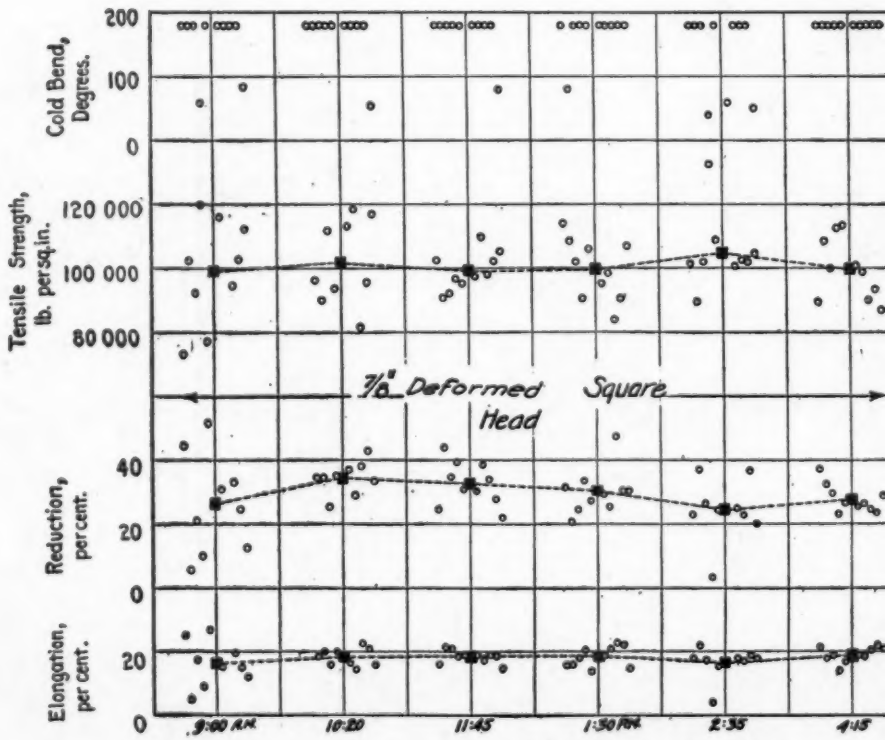


FIG. 13.—Tests on Shipment No. 1, Mill "E."

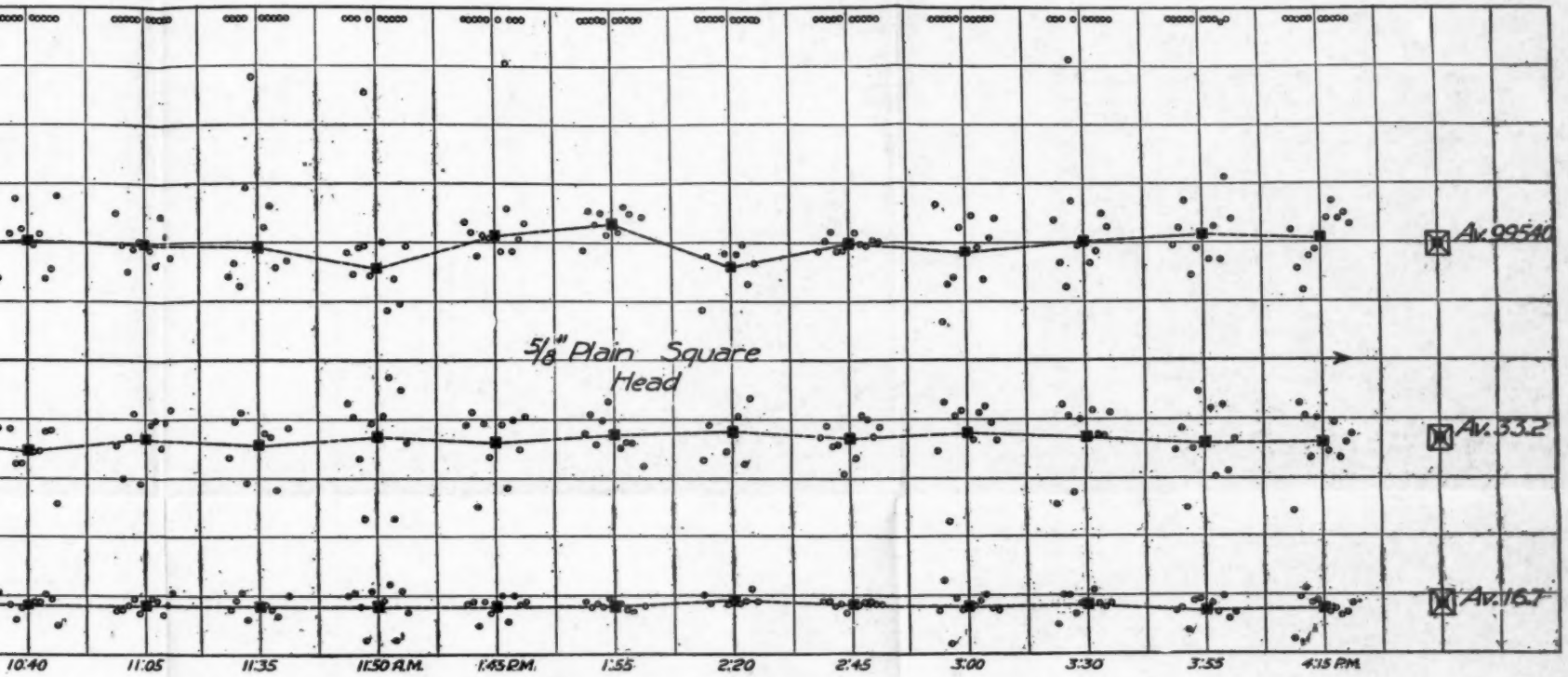
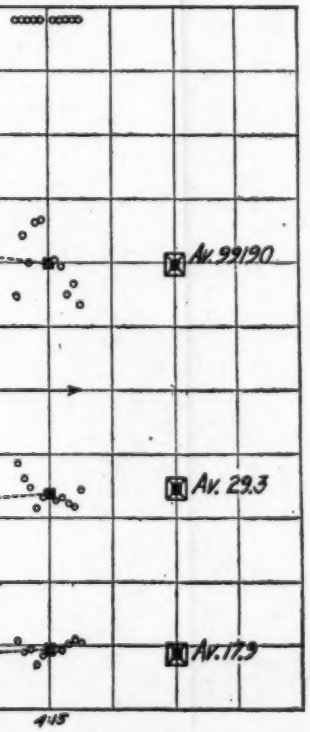


FIG. 11.—Tests on Shipment No. 1, Mill "D."



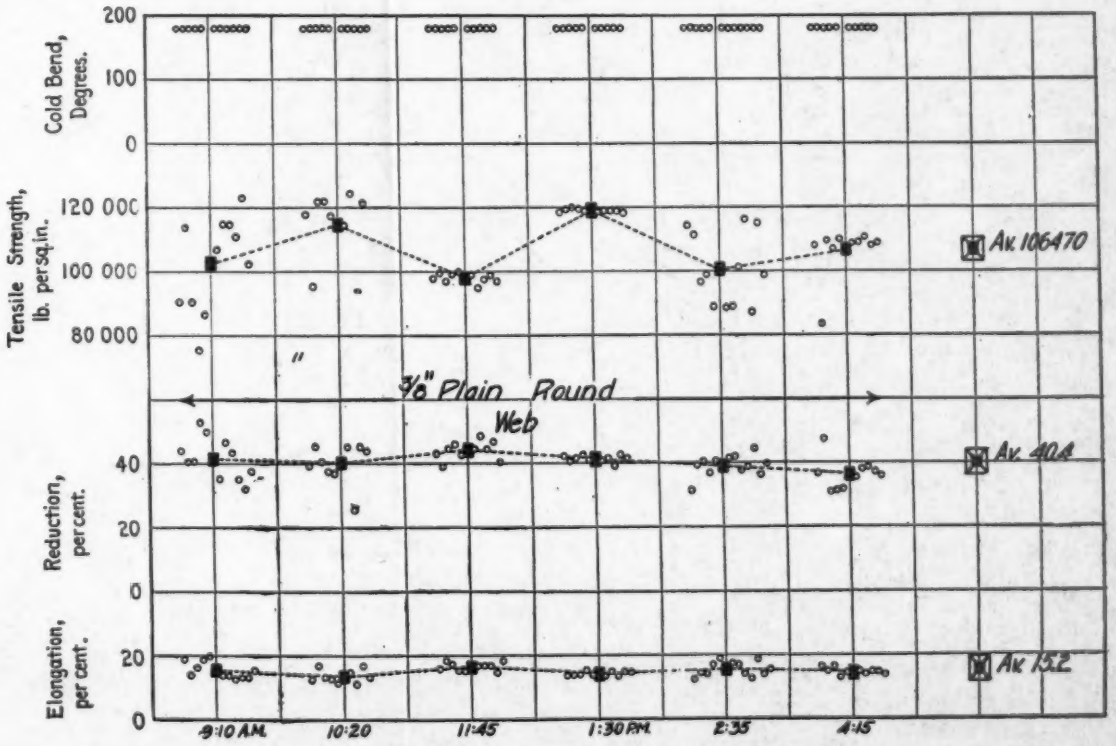


FIG. 14.—Tests on Shipment No. 1, Mill "E."

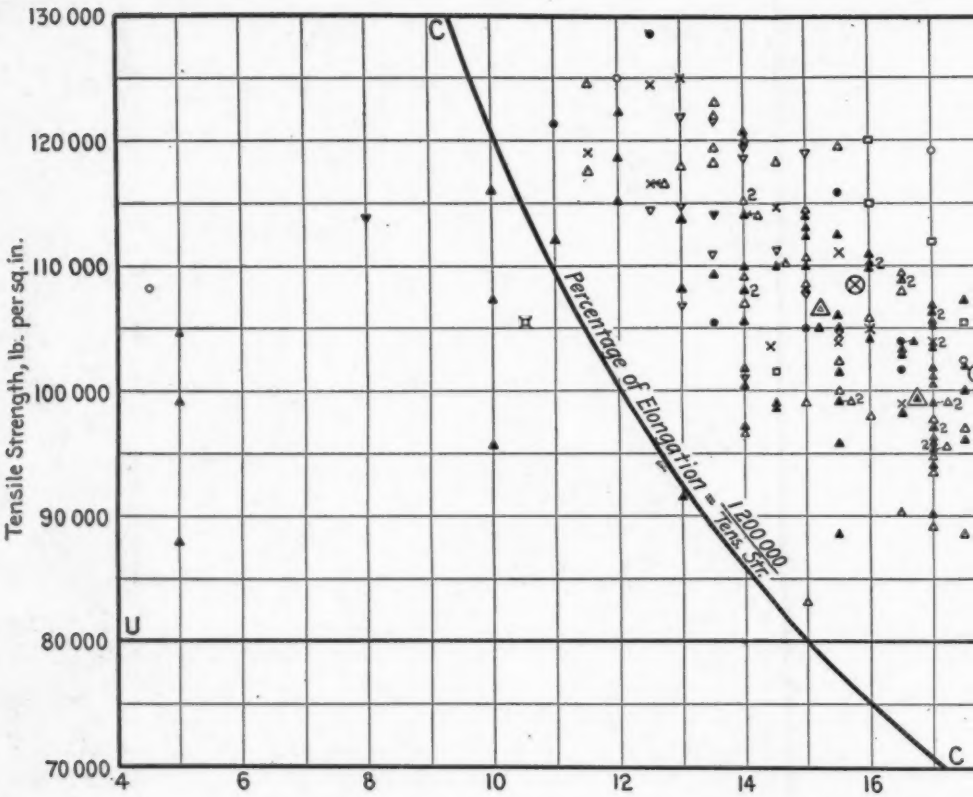
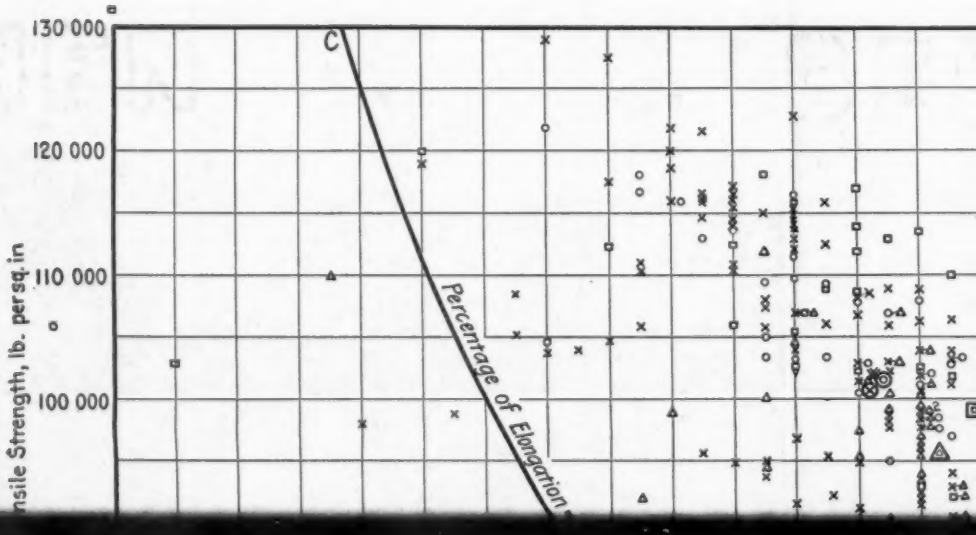
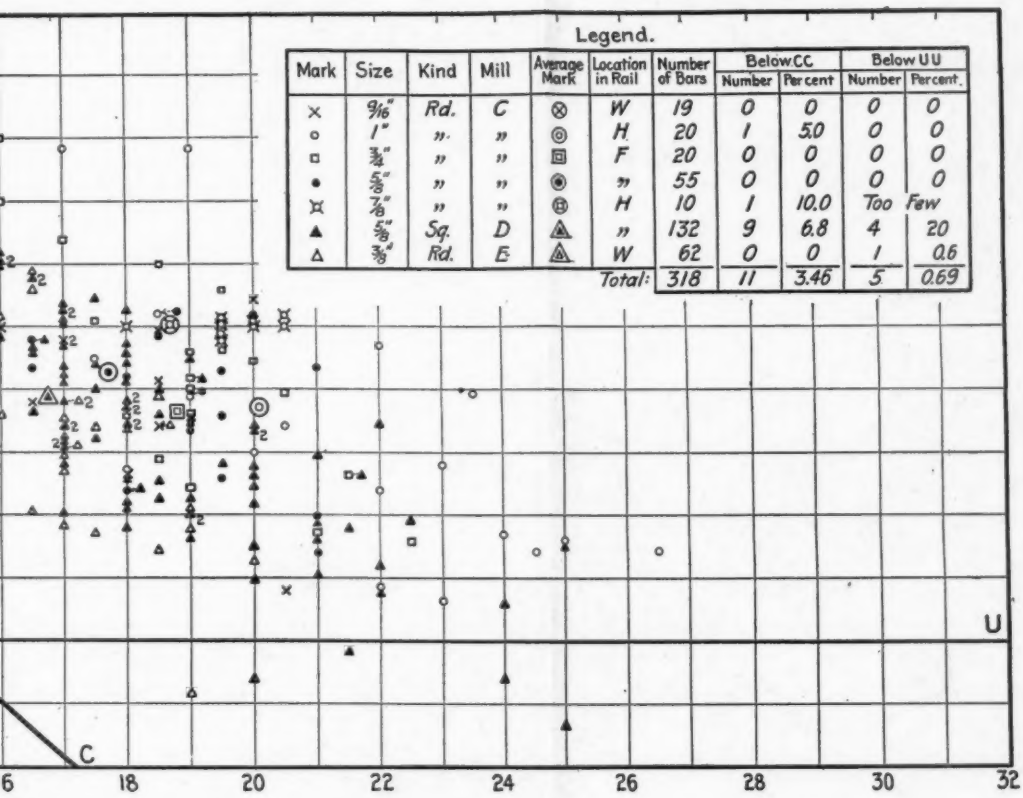


FIG. 15.—Relation between Tensile Strength



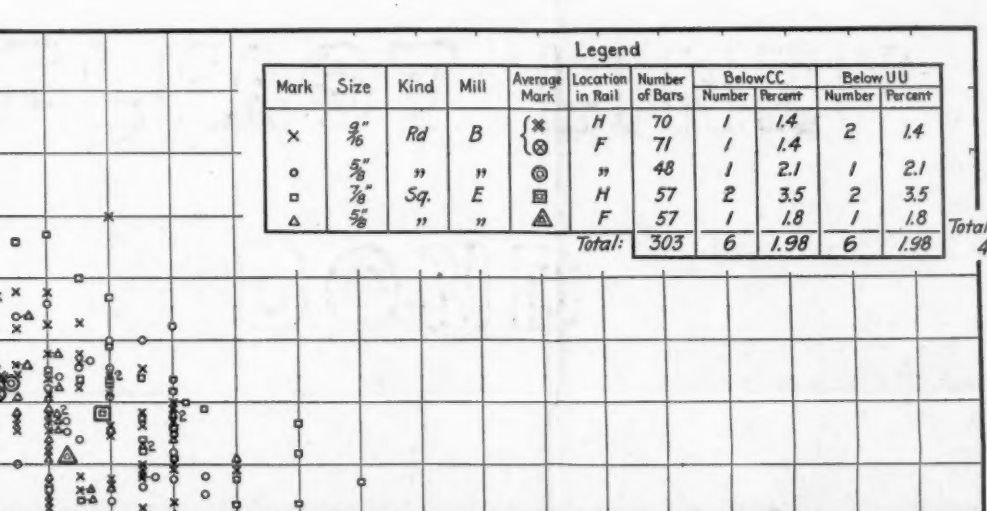


Legend.

Mark	Size	Kind	Mill	Average Mark	Location in Rail	Number of Bars	Below CC		Below U U	
							Number	Per cent	Number	Per cent.
×	9/16"	Rd.	C	⊗	W	19	0	0	0	0
○	1"	"	"	◎	H	20	1	5.0	0	0
□	3/4"	"	"	⊡	F	20	0	0	0	0
●	5/8"	"	"	◉	"	55	0	0	0	0
⌑	7/8"	"	"	⊞	H	10	1	10.0	Too	Few
▲	5/8"	Sq.	D	◬	"	132	9	6.8	4	20
△	3/4"	Rd.	E	◬	W	62	0	0	1	0.6
					Total:	318	11	3.46	5	0.69

gation, per cent

e Strength and Elongation; Individual Bars, Plain.



Legend

Mark	Size	Kind	Mill	Average Mark	Location in Rail	Number of Bars	Below CC		Below U U	
							Number	Percent	Number	Percent
×	9/16"	Rd	B	⊗	H	70	1	1.4	2	1.4
					F	71	1	1.4		
○	5/8"	"	"	◎	"	48	1	2.1	1	2.1
□	7/8"	Sq.	E	⊡	H	57	2	3.5	2	3.5
△	5/8"	"	"	◬	F	57	1	1.8	1	1.8
					Total:	303	6	1.98	6	1.98

Total percent 4.0

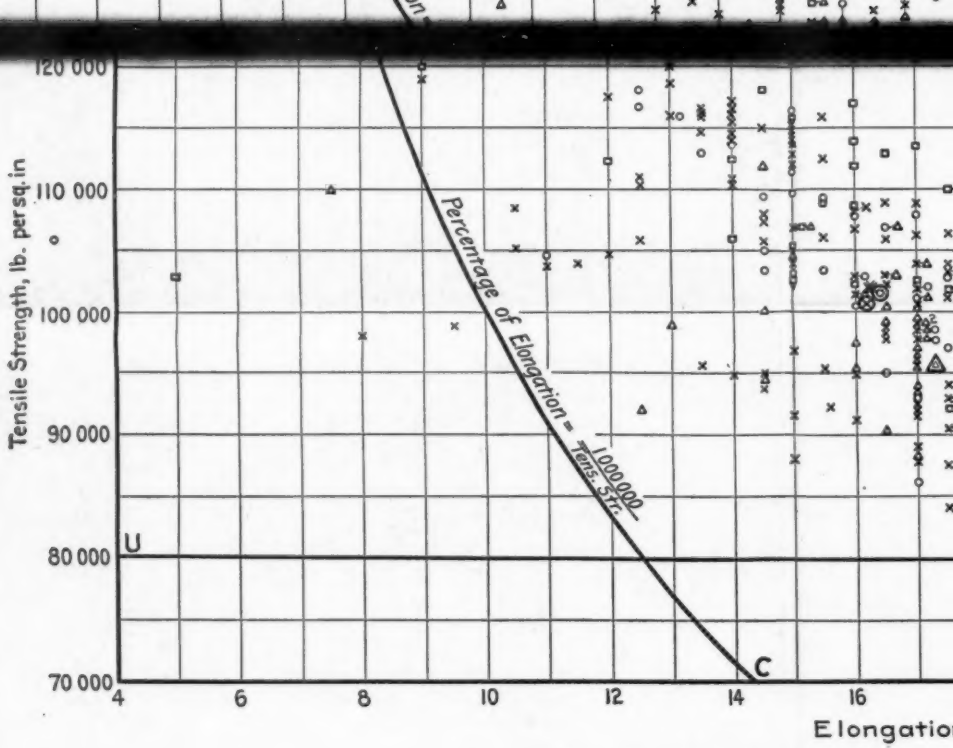


FIG. 16.—Relation between Tensile Streng

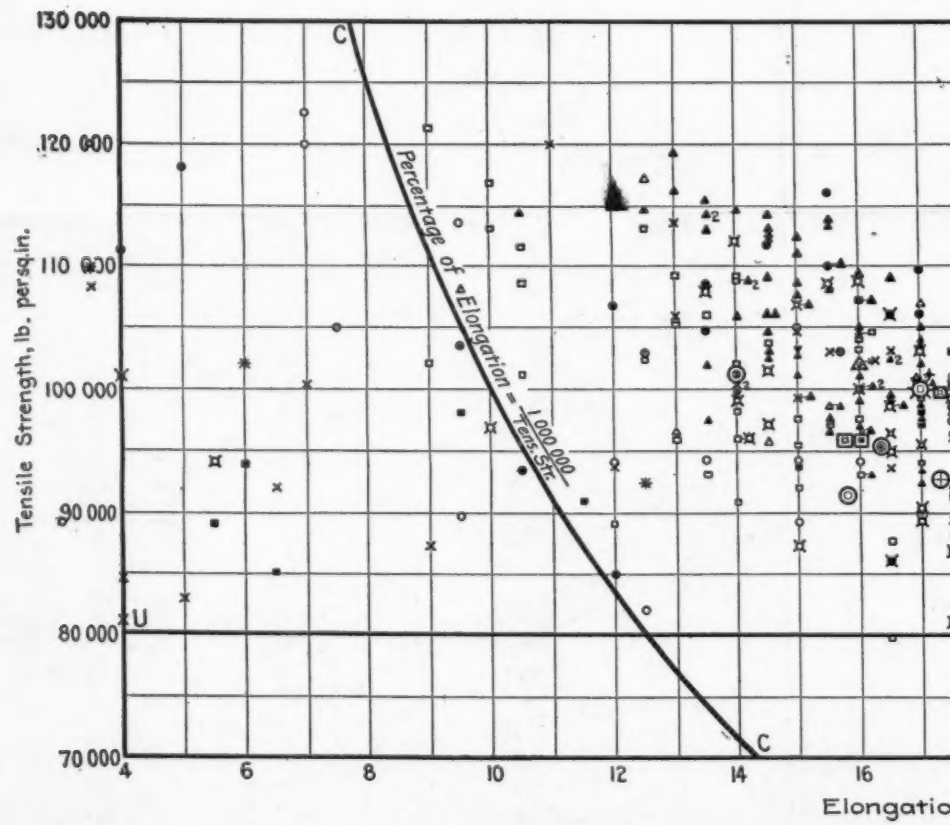
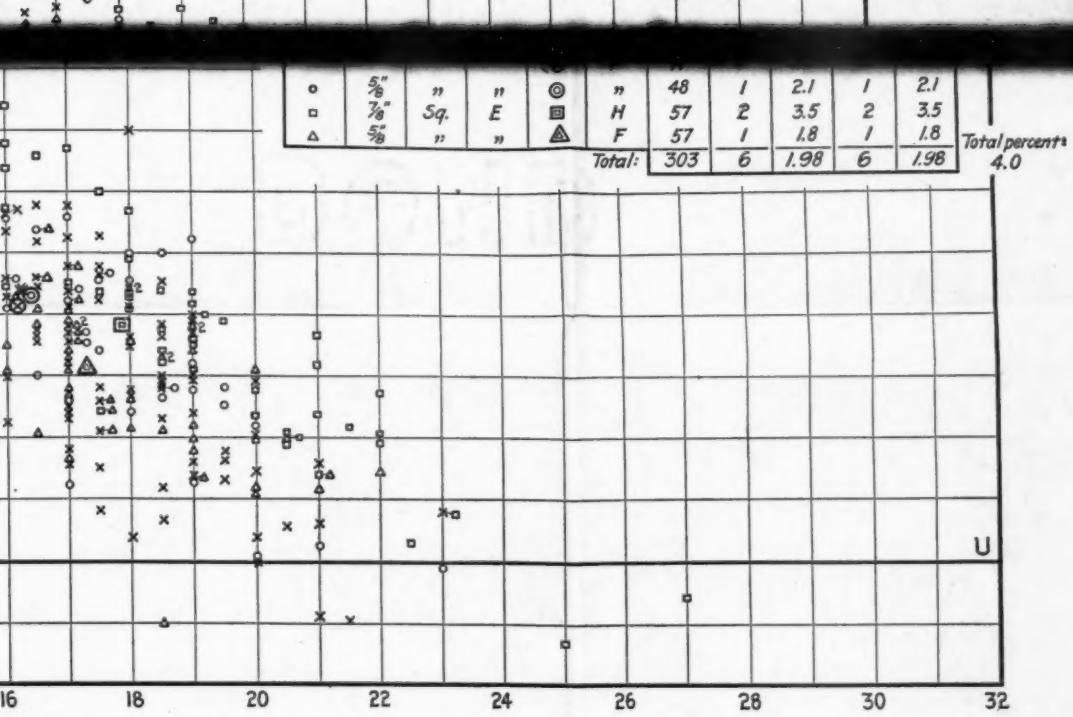


FIG. 17.—Relation between Tensile Streng



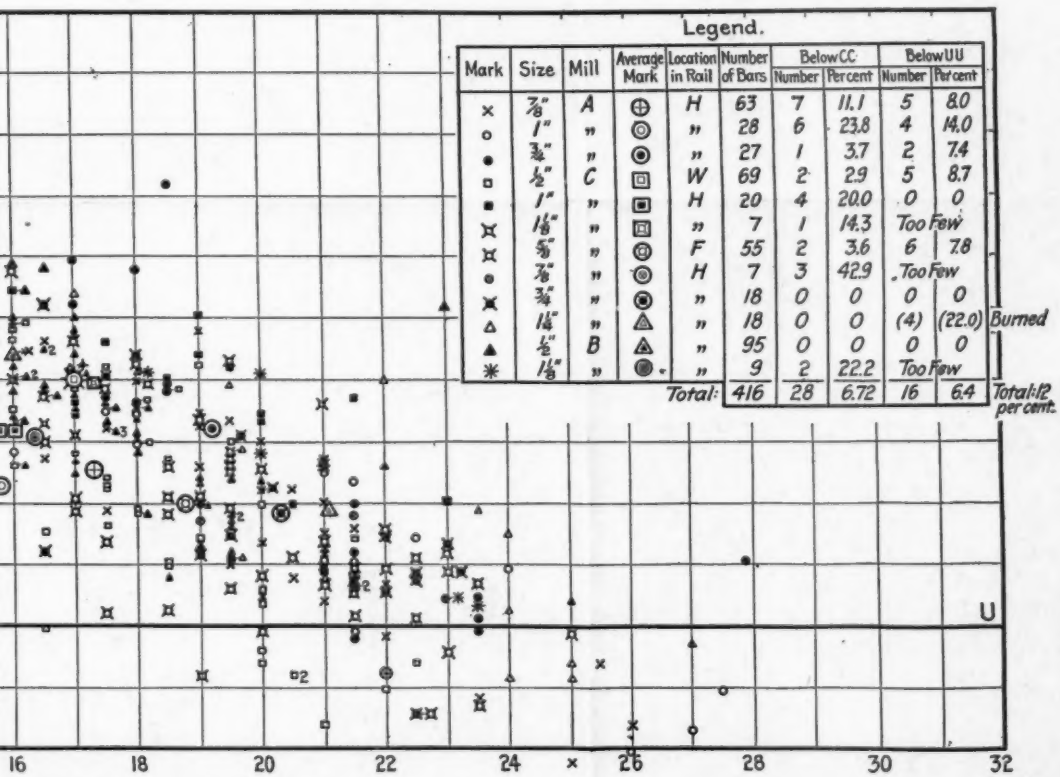
○	5/8"	"	"	◎	"	48	1	2.1	1	2.1	
□	7/8"	Sq.	E	▣	H	57	2	3.5	2	3.5	
△	5/8"	"	"	◬	F	57	1	1.8	1	1.8	Total percent 4.0
					Total:	303	6	1.98	6	1.98	

U

16 18 20 22 24 26 28 30 32

ongation, per cent.

sile Strength and Elongation; Individual Bars, Deformed.



Legend.

Mark	Size	Mill	Average Mark	Location in Rail	Number of Bars	Below CC Number	Below CC Percent	Below UU Number	Below UU Percent	
×	7/8"	A	⊕	H	63	7	11.1	5	8.0	
○	1"	"	◎	"	28	6	23.8	4	14.0	
●	3/4"	"	◉	"	27	1	3.7	2	7.4	
□	1/2"	C	▣	W	69	2	2.9	5	8.7	
■	1"	"	▣	H	20	4	20.0	0	0	
⌘	1 1/8"	"	▣	"	7	1	14.3	Too Few		
⌘	5/8"	"	◎	F	55	2	3.6	6	7.8	
●	7/8"	"	◎	H	7	3	42.9	Too Few		
⌘	3/4"	"	⊗	"	18	0	0	0	0	
△	1 1/4"	"	◬	"	18	0	0	(4)	(22.0)	Burned
▲	1/2"	B	◬	"	95	0	0	0	0	
✳	1 1/8"	"	◉	"	9	2	22.2	Too Few		
				Total:	416	28	6.72	16	6.4	Total: 12 per cent.

U

16 18 20 22 24 × 26 28 30 32

longation . per cent.

ile Strength and Elongation; Individual Bars, Twisted.

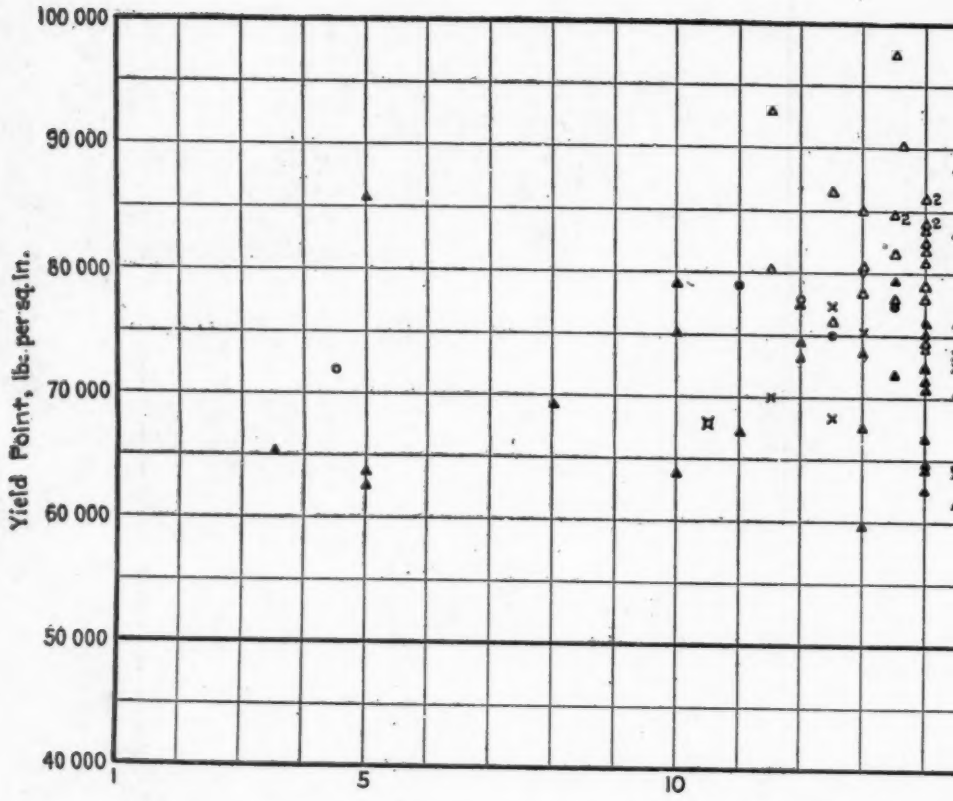
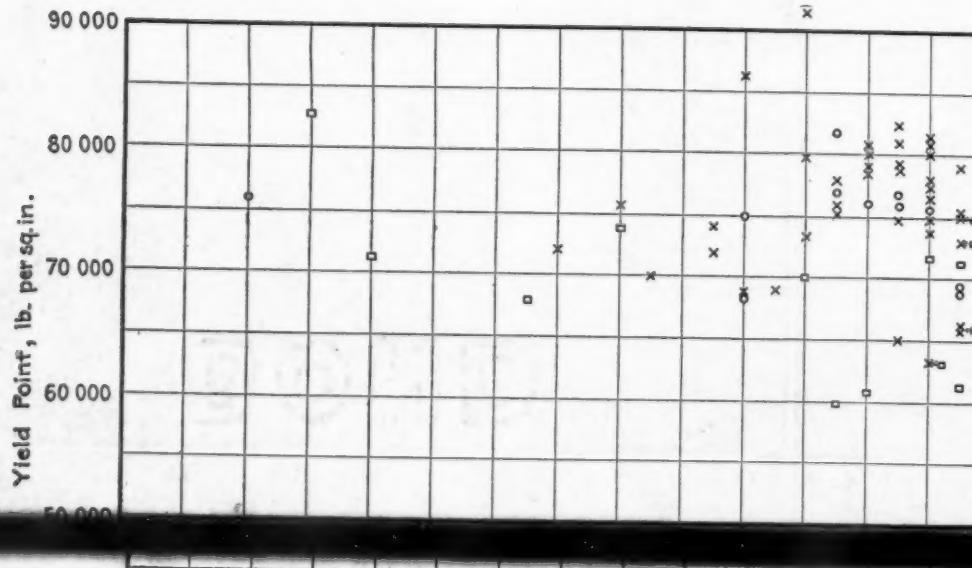
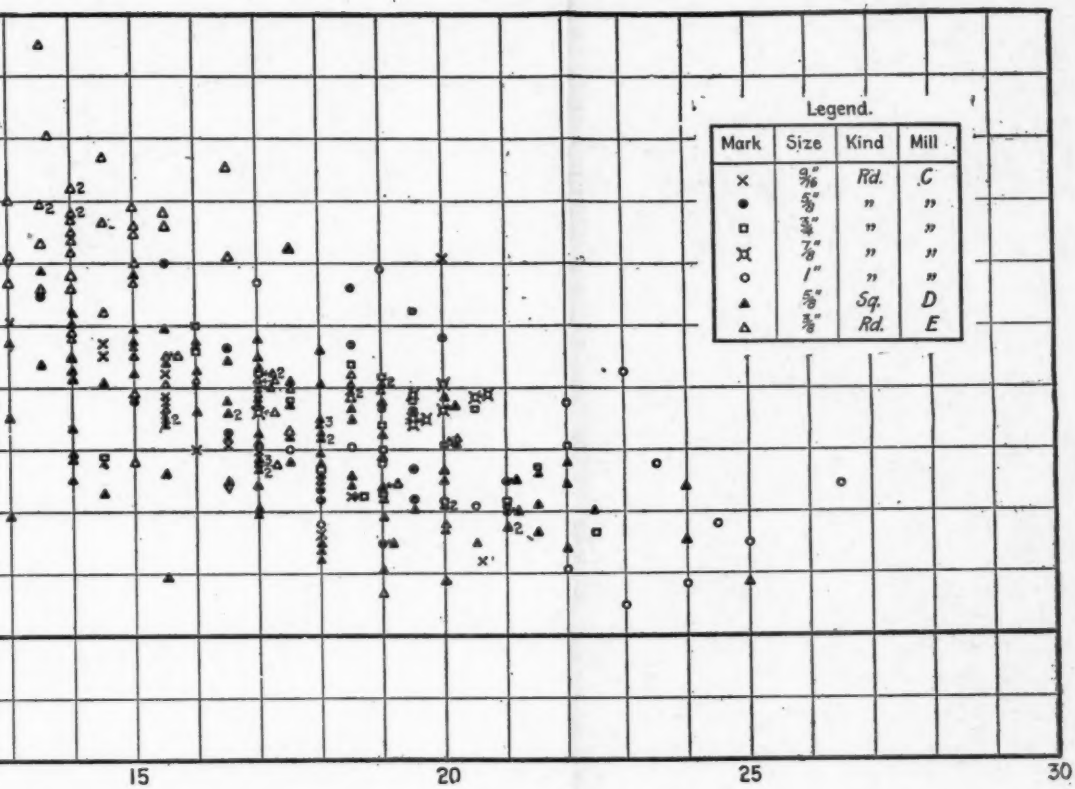


FIG. 18.—Relation between Yield





gation, per cent.

veen Yield Point and Elongation; Individual Bars, Plain.

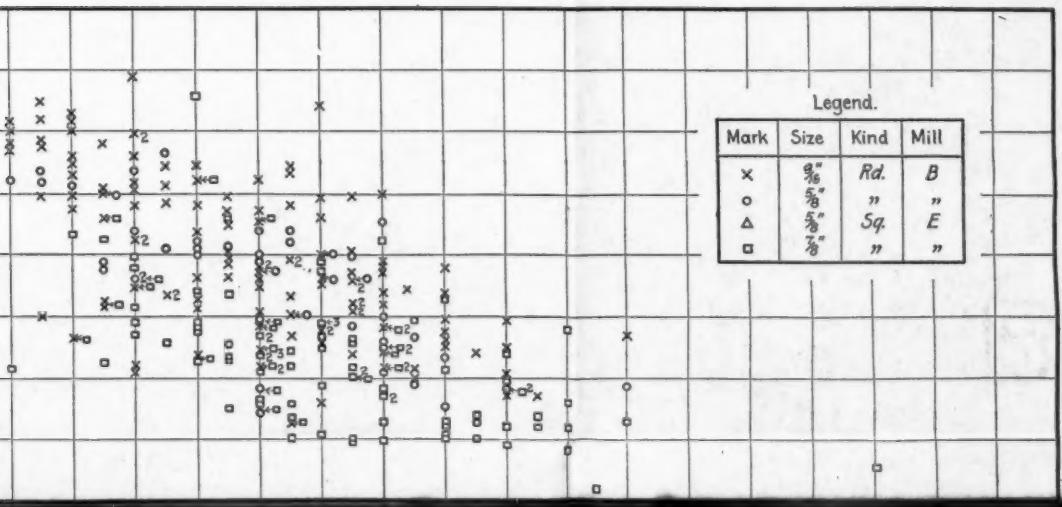




FIG. 18.—Relation between Yield

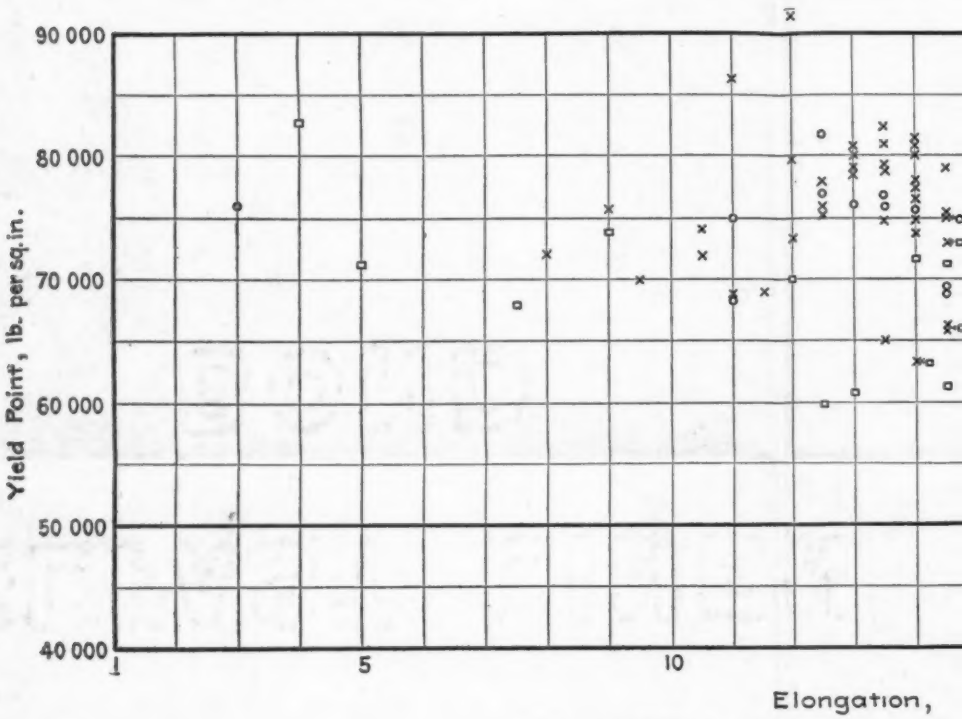


FIG. 19.—Relation between Yield Point a

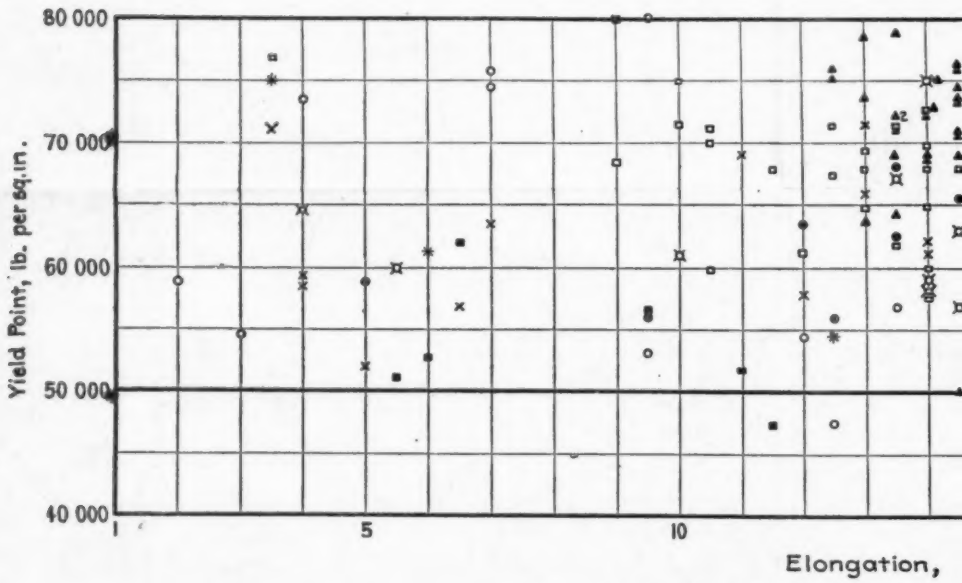
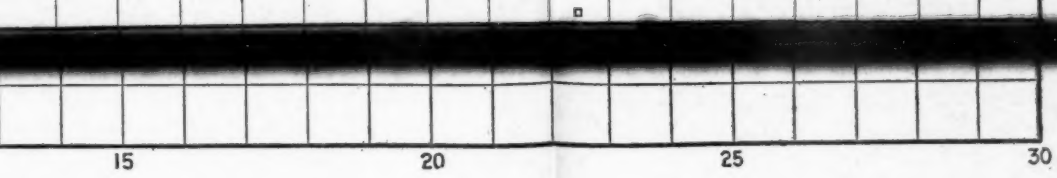
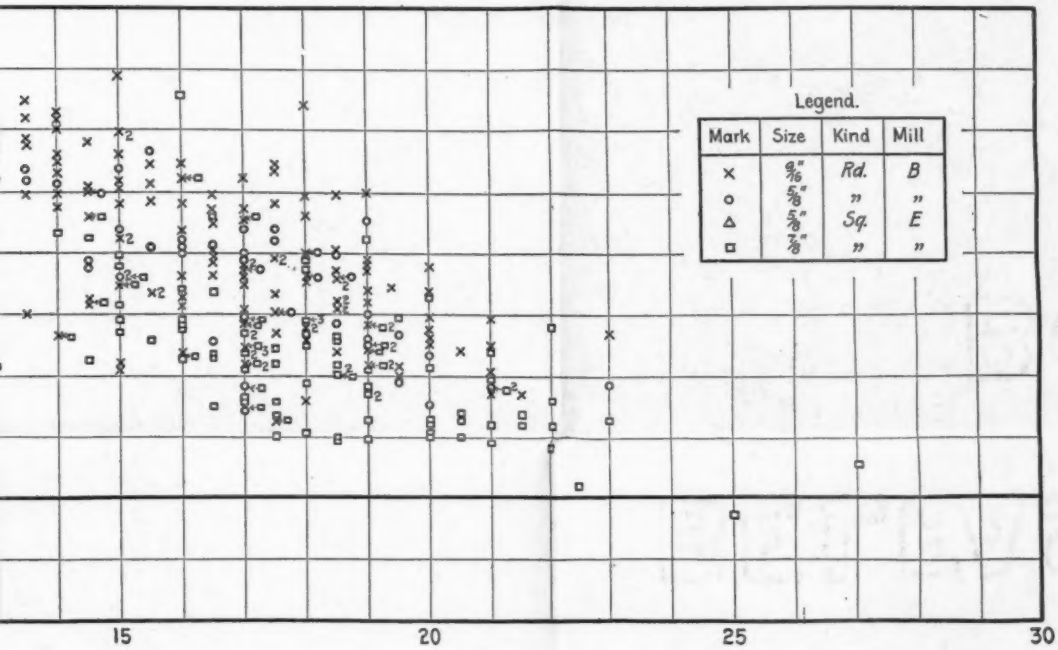


FIG. 20.—Relation between Yield Point



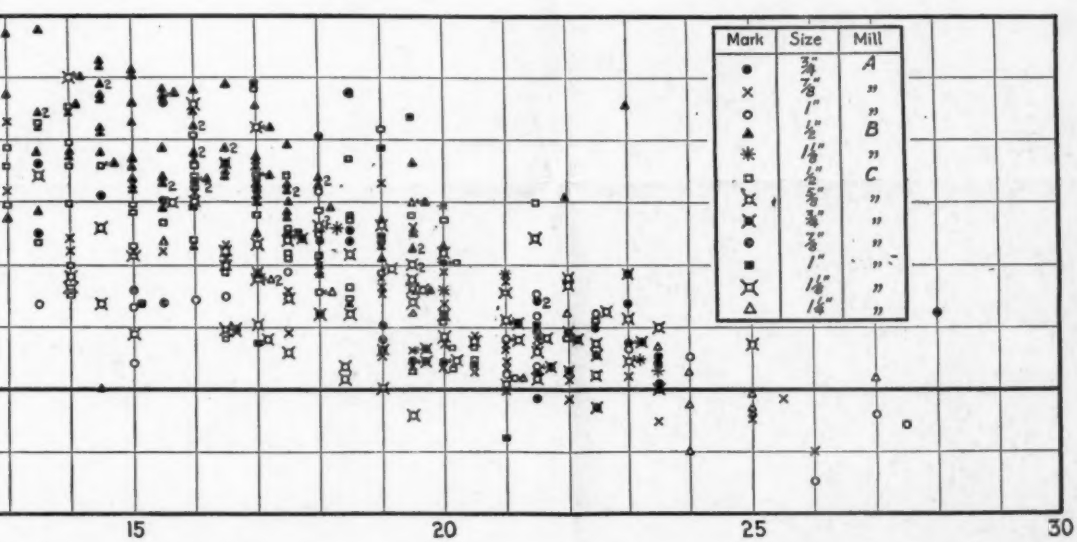
ation, per cent.

een Yield Point and Elongation; Individual Bars, Plain.



ation, per cent

d Point and Elongation; Individual Bars, Deformed.



gation, per cent.

eld Point and Elongation; Individual Bars, Twisted.

TABLE IV.—GENERAL RESULTS FOR BARS BREAKING IN GAGE.

TWISTED BARS.

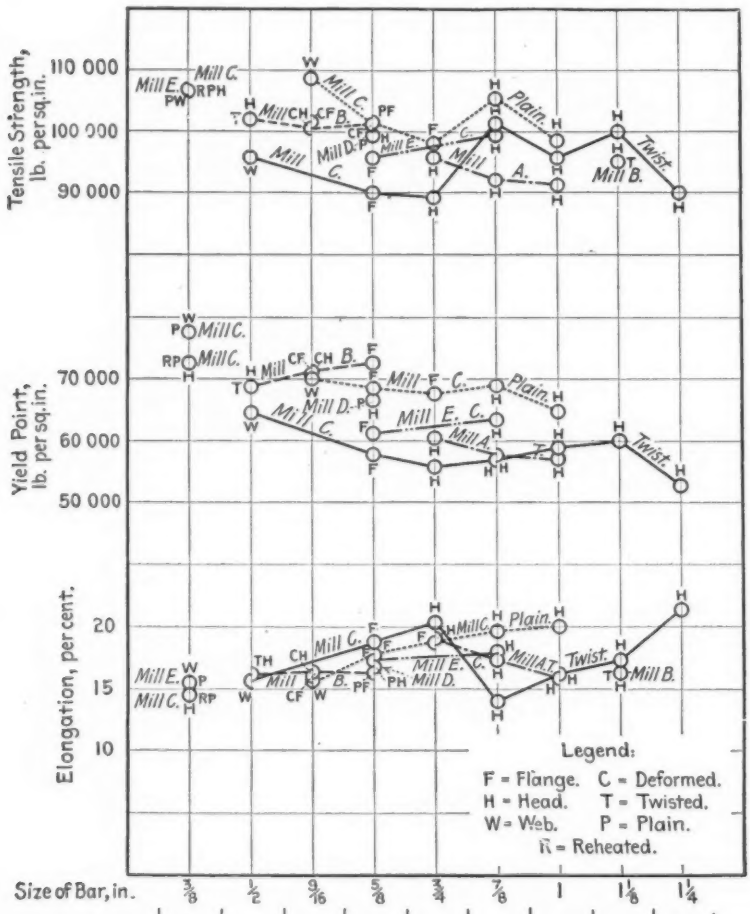
Tensile Strength, lb. per sq. in.

Size of Bar.	MILL.					
	A	B	C	D	E	
½-in.	.....	102 050	95 780	.....	.....	.....
⅝ "	.....	.....	90 000	.....	.....	.....
¾ "	95 920	.....	89 130	.....	.....	.....
⅞ "	92 100	.....	101 400	.....	.....	.....
1 "	91 250	.....	95 980	.....	.....	.....
1⅛ "	.....	95 070	99 730	.....	.....	.....
1¼ "	.....	.....	89 560	.....	.....	.....
Elongation, per cent.						
½-in.	.....	16.0	15.8	.....	.....	.....
⅝ "	.....	.....	18.8	.....	.....	.....
¾ "	19.2	.....	20.3	.....	.....	.....
⅞ "	17.3	.....	14.0	.....	.....	.....
1 "	15.8	.....	16.0	.....	.....	.....
1⅛ "	.....	16.4	17.3	.....	.....	.....
1¼ "	.....	.....	21.1	.....	.....	.....

OTHER BARS.

Tensile Strength, lb. per sq. in.

		Def. Rd.	Pl. Rd.	Pl. Sq.	Pl. Rd.	Def. Sq.
⅜-in.	.....	.....	.....	.....	106 70	.....
9/16 "	.....	101 220	108 570	.....	.....	.....
⅝ "	.....	101 650	101 420	99 540	.....	95 660
¾ "	.....	.....	98 270	.....	.....	.....
⅞ "	.....	.....	105 130	.....	.....	99 160
1 "	.....	.....	98 680	.....	.....	.....
Elongation, per cent.						
⅜-in.	.....	.....	.....	.....	15.2	.....
9/16 "	.....	16.24	15.8	.....	.....	.....
⅝ "	.....	16.4	17.7	16.74	.....	17.3
¾ "	.....	.....	18.8	.....	.....	.....
⅞ "	.....	.....	18.7	.....	.....	17.9
1 "	.....	.....	20.1	.....	.....	.....



Kind of Bar.	Number of each Size of Bars.									Total.
Twisted		*159*		*55*	*45*	*60*	*48*	*16*	*18*	*401*
Plain	*82*		*19*	*152*	*20*	*10*	*20*			*303*
Deformed			*139*	*105*		*57*				*301*
(Reheated)	*(20)*									
Total :	*82*	*159*	*158*	*312*	*65*	*127*	*68*	*16*	*18*	*1005*

FIG. 21.—Relation of Size to Average Strength, Yield Point and Elongation.

This has been done in Fig. 22, on which have also been drawn:

1. Howe's lines of common greatest and least elongation for various grades of steel.[1]

2. Tetmajer's curve of good quality of steel, that is:

Elongation = 1,500,000 ÷ tensile strength.

It will be seen from these (1) that the rerolled steel has an

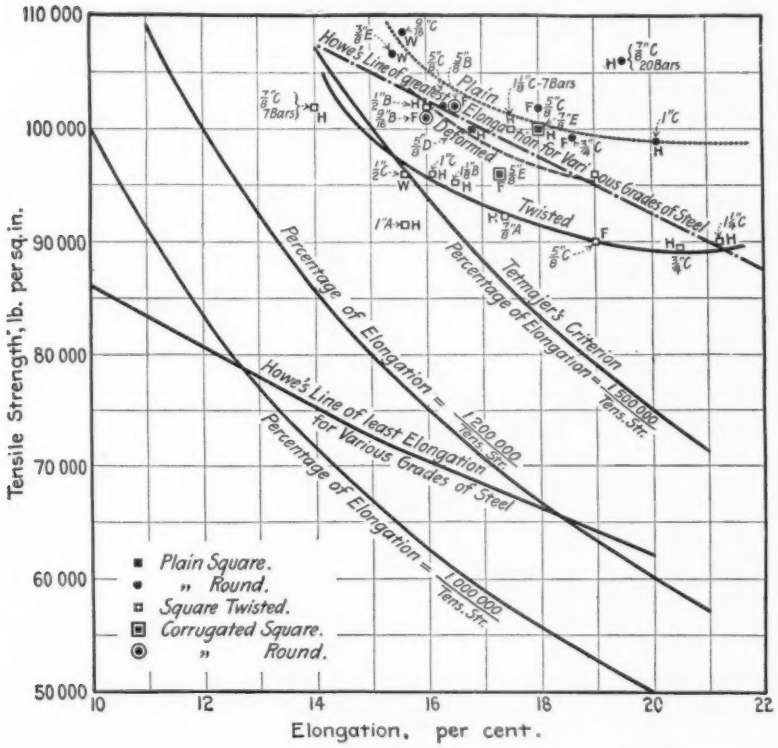


FIG. 22.—Relation between Average Tensile Strength and Elongation.

excess ductility for its strength above usual grades of steel; and (2) that the twisted bars yield, as a rule, a smaller product of strength and elongation than the plain or deformed bars.

From Fig. 22, Fig. 23 has been prepared from which the relation between tensile strength and elongation for averages

[1] "Metallurgy of Steel," H. M. Howe.

may be obtained. These values should, of course, be reduced in specification requirements, since they apply to averages. Following is a numerical statement of the relation between strength and elongation:

Kind of Bars.	Percentage of Elongation times Tensile Strength.	Percentage of Elongation times Yield Point.
Plain	1 650 000 – 2 000 000	900 000 – 1 380 000
Deformed	1 700 000	1 050 000 – 1 137 000
Twisted	1 400 000 – 1 900 000	750 000 – 1 220 000

For individual tests see Figs. 15 to 20, Plates III and IV.

By reference to the averages shown in Fig. 22, these tests disclose a product with the following average mechanical properties:

Properties Considered.	Range of Average Properties.	
	Deformed and Plain Bars.	Hot-twisted Bars.
Tensile strength, lb. per sq. in.	98 600 – 108 500	90 000 – 102 000
Yield point, lb. per sq. in.	60 000 – 75 000	55 000 – 65 000
Elongation in 8 in., per cent	15.2 – 20.1	14.0 – 21.1

Bend Tests.—An estimate of the degree of bending to which these bars will submit may be obtained from Table V, Plate V, which is abstracted as follows:

Plain and Deformed Bars.

Under $\frac{3}{4}$ *in.*—97.0 per cent of the bars bent to 180 deg.; minimum single bend was 55 deg.

$\frac{3}{4}$ *in. and over.*—97.6 per cent of the bars bent to 90 deg.; minimum single bend was 40 deg.

Twisted Bars.

Under $\frac{3}{4}$ *in.*—96.5 per cent of the bars bent to 180 deg.; minimum single bend was 75 deg.

$\frac{3}{4}$ *in. and over.*—93.2 per cent of the bars bent to 180 deg.; minimum single bend was 20 deg.

TABLE V.—BEND TESTS: PERCENTAGE OF BARS BENDING TO VARIOUS ANGLES.

TWISTED BARS.

Size of Bar.	Mill.	Angle in Degrees.																								Total Number of Bars.
		180	175	167	165	160	155	150	145	140	135	130	127	125	120	115	105	85	78	75	60	50	45	30	25	20	
$\frac{7}{8}$-in.	A	71.6	73.6	....	75.5	....	....	....	81.1	....	84.1	....	....	.....	....	86.8	90.5	92.5	.....	94.3	....	96.2	....	98.1	100.0	.....	53
$\frac{3}{4}$ "	"	100.0	....	....	....	....	....	....	.....	....	....	....	....	.....	....	....	....	.....	.....	.....	....	....	....	....	.....	.....	27
1 "	"	60.7	64.3	....	....	....	67.8	....	.....	71.4	....	....	....	.....	75.0	....	....	78.6	.....	85.7	89.3	....	96.4	....	.....	100.0	28
$\frac{1}{2}$ "	B	100.0	....	....	....	....	....	....	.....	....	....	....	....	.....	....	....	....	.....	.....	.....	....	....	....	....	.....	.....	95
$1\frac{1}{8}$ "	"	77.8	....	....	....	....	....	....	.....	....	....	....	88.9	.....	....	....	....	.....	100.0	.....	....	....	....	....	.....	.....	9
$\frac{1}{2}$ "	C	94.0	....	....	....	....	....	....	.....	....	95.5	....	....	.....	....	....	97.0	98.5	.....	100.0	....	....	....	....	.....	.....	66
$\frac{1}{2}$ "	All	97.5	....	....	....	....	....	....	.....	....	98.1	....	....	.....	....	....	98.8	99.4	.....	100.0	....	....	....	....	.....	.....	161
$\frac{5}{8}$ "	C	94.5	96.4	....	....	98.2	....	....	.....	....	....	....	....	.....	....	....	....	100.0	.....	.....	....	....	....	....	.....	.....	55
$\frac{7}{8}$ "	"	71.4	....	....	....	....	....	....	100.0	....	....	....	....	.....	....	....	....	.....	.....	.....	....	....	....	....	.....	.....	7
$\frac{7}{8}$ "	All	71.6	73.4	....	75.0	....	....	....	83.3	....	86.7	....	....	.....	....	88.3	91.7	93.3	.....	95.0	....	96.7	....	98.3	100.0	.....	60
$\frac{3}{4}$ "	C	100.0	....	....	....	....	....	....	.....	....	....	....	....	.....	....	....	....	.....	.....	.....	....	....	....	....	.....	.....	19
$\frac{3}{4}$ "	All	100.0	....	....	....	....	....	....	.....	....	....	....	....	.....	....	....	....	.....	.....	.....	....	....	....	....	.....	.....	46
1 "	C	81.0	....	....	85.7	....	....	....	.....	....	....	....	....	.....	....	90.5	....	95.2	.....	100.0	....	....	....	....	.....	.....	21
1 "	All	69.4	71.4	....	73.4	....	76.5	....	.....	77.6	....	....	....	.....	79.6	81.6	....	85.7	.....	91.8	93.9	....	98.0	....	.....	100.0	49
$1\frac{1}{8}$ "	C	100.0	....	....	....	....	....	....	.....	....	....	....	....	.....	....	....	....	.....	.....	.....	....	....	....	....	.....	.....	7
$1\frac{1}{8}$ "	All	87.5	....	....	....	....	....	....	.....	....	....	....	93.8	.....	....	....	....	.....	100.0	.....	....	....	....	....	.....	.....	16
$1\frac{1}{4}$ "	C	76.5	....	82.4	....	88.2	....	94.1	....	....	....	....	....	100 0	....	....	....	.....	.....	.....	....	....	....	....	.....	.....	17

PLAIN BARS.

Size and Kind of Bar.	Mill.	Angle in Degrees.							Total Number of Bars.
		180	175	160	110	105	80	55	
$\frac{9}{16}$-in. Pl. Rd.	C	100.0	....	....	....	....	.....	.....	20
$\frac{5}{8}$ " "	"	100.0	....	....	....	....	.....	.....	20
$\frac{7}{8}$ " "	"	100.0	....	....	....	....	.....	.....	10
$\frac{3}{4}$ " "	"	100.0	....	....	....	....	.....	....	20
1 " "	"	90.0	....	95.0	.....	.....	100.0	.....	20
$\frac{5}{8}$-in. Pl. Sq.	D	97.0	97.7	....	98.5	99.2	.....	100.0	132
$\frac{3}{8}$-in. Pl. Rd.	E	100.0	....	....	....	....	.....	.....	62

DEFORMED BARS.

Size and Kind of Bar.	Mill.	Angle in Degrees.										Total Number of Bars.
		180	130	120	115	85	80	60	55	50	40	
$\frac{9}{16}$-in Co. Rd.	B	98.6	99.3	.....	100.0	....	....	....	....	....	.....	138
$\frac{5}{8}$ " "	B	97.9	....	100.0	.....	....	....	....	....	....	.....	48
$\frac{7}{8}$-in. Co. Sq.	E	86.2	....	.....	.....	88.0	91.4	94.9	96.5	98.3	100.0	58
$\frac{7}{8}$ " "	E	98.2	....	.....	100.0	....	....	....	....	....	.....	57

NOTE.—The heavy lines indicate the specification limit of angle of bend; thus, the larger bars are required to bend to 90 degrees, and the smaller bars 1ot 80 degrees.

The writer believes that the diameter of pin specified for the larger bars is not in correct relation to that specified for the smaller bars. If a bar less than $\frac{3}{4}$ in. calls for a pin of diameter three times the thickness of the test bar, with a bend of 180 deg., then the larger bars should bend 90 deg. around a pin of diameter six times the thickness of the test bar. The present specifications provide a pin of diameter four times the thickness of the bar.

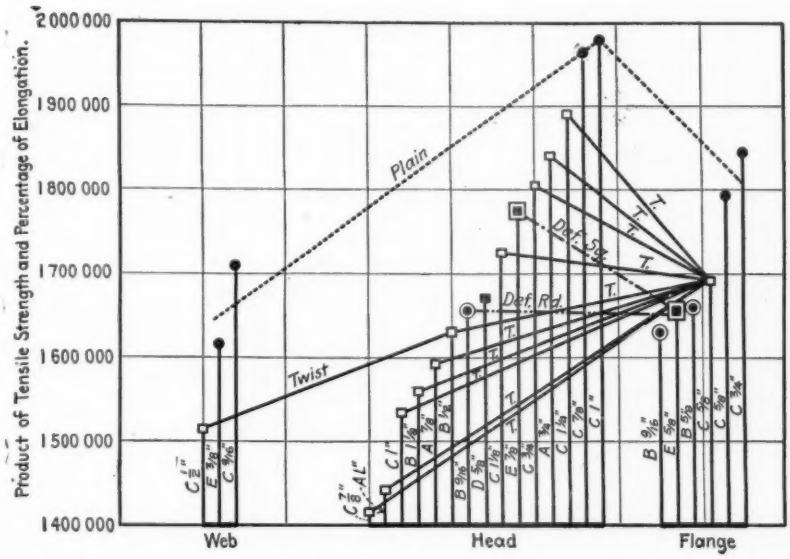


FIG. 23.—Quality Factors

EFFECT OF VARIOUS FACTORS UPON THE RESULTS.

The samples were collected to represent the output under commercial mill conditions, so that there was no attempt, except in the series of new rails, to impose artificial conditions necessary to determine the effect due to the continued variation of each of the several factors, namely: design of bar, size of bar, original position in rail, kind of rail, mill practice, rolling temperature, rate of cooling, and size of rail. However, a wide range of kind and size of bar was secured, and the samples permit a com-

parison of these variable factors. The comparisons are shown in diagrammatic form.

The qualities of the various sizes of bars are of course affected by the amount of reduction, the rolling temperature and rate of

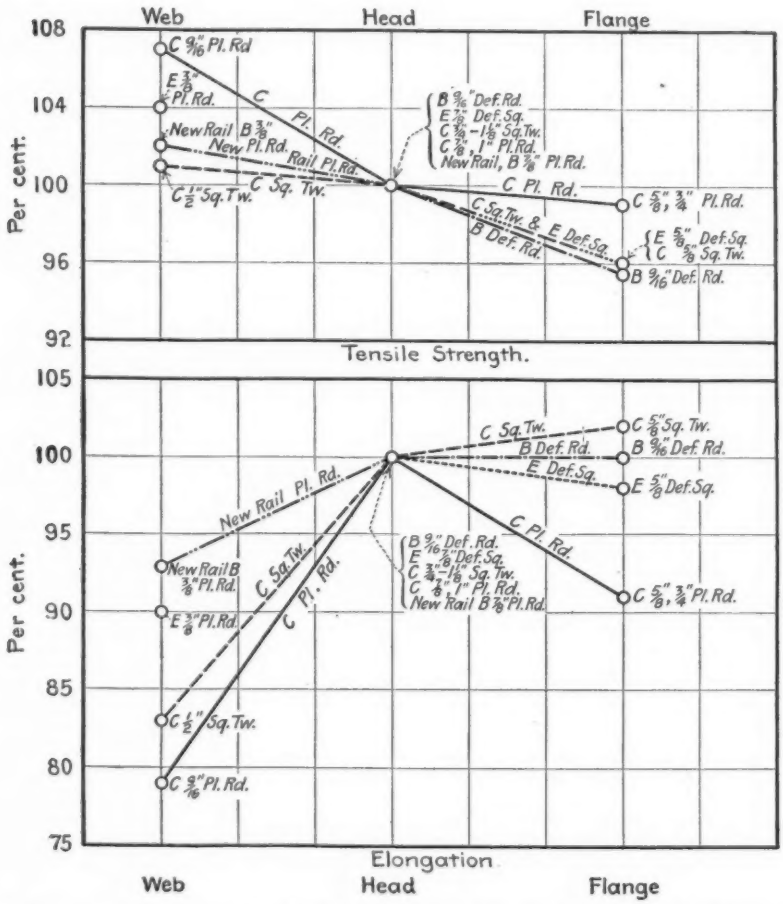


FIG. 24.—Comparison of Material from Head, Web and Flange, in Per Cent.

cooling, and also by the fact that the larger bars come usually from the head of the rail; so that, as a matter of fact, the size and position in the rail are interdependent.

The origin of the material is, however, the most persistent

factor, as is shown in Table VI and Fig. 24, so that in determining effects of size and design we will separate first as to origin.

TABLE VI.—COMPARISON OF POSITION IN RAIL.

OLD RAILS.

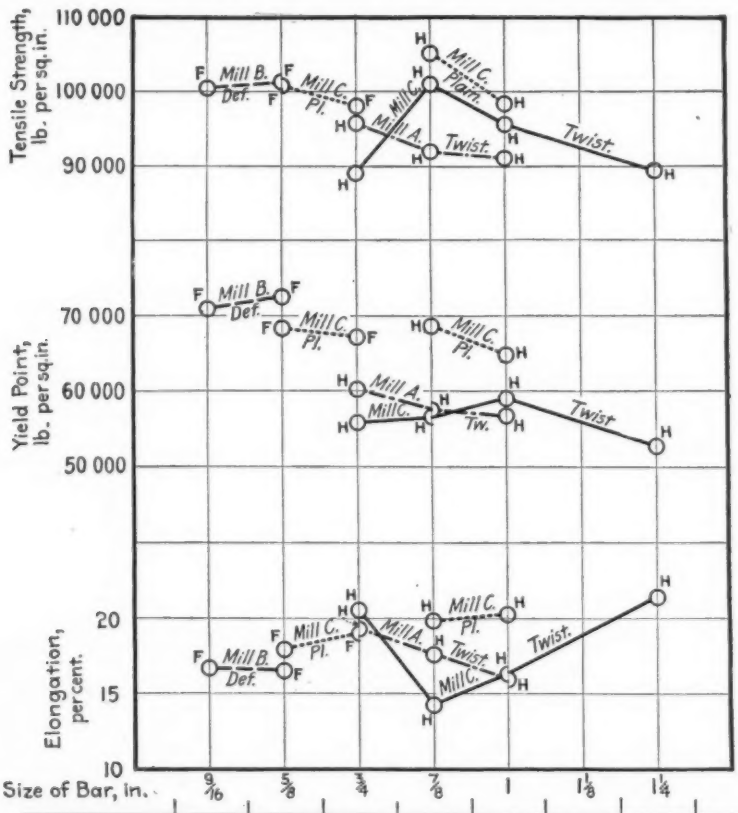
Size and Kind of Bar.	Mill.	Position in Rail.	Tensile Strength.		Elongation.	
			lb. per sq. in.	Ratio.	Per cent.	Ratio.
$\frac{9}{16}$-in. Cor. Rd.	B	Head....	101 650	100.0	16.3	100
$\frac{9}{16}$ " "	"	Flange...	100 810	95.5	16.2	100
$\frac{7}{8}$-in. Cor. Sq.	E	Head....	99 190	100.0	17.9	100
$\frac{5}{8}$ " "	"	Flange...	95 660	96.0	17.3	98
$\frac{3}{8}$-in. Pl. Rd.	"	Web.....	106 470	104.0	15.2	90
$\frac{3}{4}$-1$\frac{1}{8}$-in. Sq. Tw.	C	Head....	93 480	100.0	18.1	100
$\frac{5}{8}$-in. Sq. Tw.	"	Flange...	90 000	96.0	18.8	102
$\frac{1}{2}$ " "	"	Web.....	95 780	101.0	15.8	83
$\frac{7}{8}$-1-in. Pl. Rd.	"	Head....	100 830	100.0	20.0	100
$\frac{5}{8}$-$\frac{3}{4}$ " "	"	Flange...	99 840	99.0	18.2	91
$\frac{9}{16}$-in. Pl. Rd.	"	Web.....	108 570	107.0	15.8	79
NEW RAILS.						
$\frac{7}{8}$-in. Pl. Rd.	B	Head....	92 680	100.0	20.2	100.0
$\frac{3}{8}$ " "	"	Web.....	96 590	102.0	18.8	93.0

1. *Comparison of Material from Head, Web and Flange.*—(See Table VI and Fig. 24.) These diagrams show a distinct classification of material upon the basis of its origin. The web bars are harder than those from the head, and the flange bars softer than the head bars. Thus with the head as 100 per cent:

Position in Rail.	Relative Tensile Strength.	Relative Elongation.
Web.....	103.7	86.0
Head.....	100.0	100.0
Flange.....	95.0	98.0

2. *Comparison of Size of Bar.*—(See Fig. 25.) In this diagram the groups of like origin and mill manufacture have been connected. The general tendency of each group is seen

to be toward a decrease of strength and an increase of elongation as the size of bars increases. However, part of this general tendency for all the groups considered together is



Kind of Bar.	Number of each Size of Bars.							Total.
Twisted			A 27	A 53	A 28			108
			C 18	C 7	C 20		C 18	63
Plain		C 20	C 20	C 10	C 20			70
Deformed	B 70	B 48						118
Total:	70	68	65	70	68		18	359

FIG. 25.—Effect of Size of Bars.

due to the fact that the larger sizes of bars were twisted bars.

3. *Comparison of Design of Bar.*—(See Fig. 26.) These diagrams separate the bars on the basis of origin in the rail.

The plain round bars are the strongest and the twisted bars the weakest. Thus, for material from the flange:

Design of Bars.	Tensile Strength, lb. per sq. in.	Elongation, per cent.
Plain Round	99 800	18.2
Deformed Round	101 400	16.3
Deformed Square	95 600	17.3
Square Twisted	90 000	18.8

In the case of material from the head of the rail, the indications are not so clear. The various designs of smaller bars

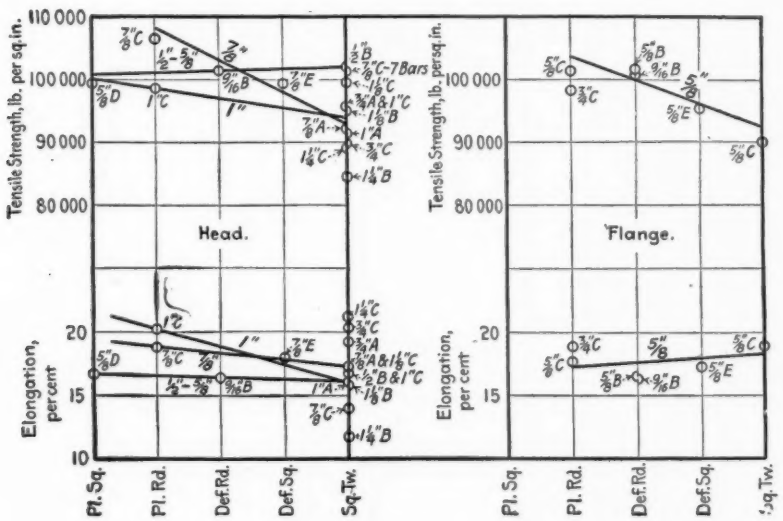


FIG. 26.—Comparison of Design of Bar.

are of practically the same quality, but the twisted bars of large size are of less strength than the other designs. This is partly accounted for by the showing in Table III, where it appears that the harder twisted bars of large size have been automatically weeded out from the averages because they broke mainly outside the gage length.

4. *Size of Rail.*—The results of the tests from rails of varying sections are given in Table VII and Fig. 27.

5. *Relation between Rerolled Bars and Original Rail.*—A special series of tests was made to determine:

(*a*) Relation between the rerolled bar and the original rail;

(*b*) Changes in mechanical properties at successive passes.

For this purpose new rails were used because it was thus possible to secure several rails of known and uniform composition. In this way the one changing condition could be

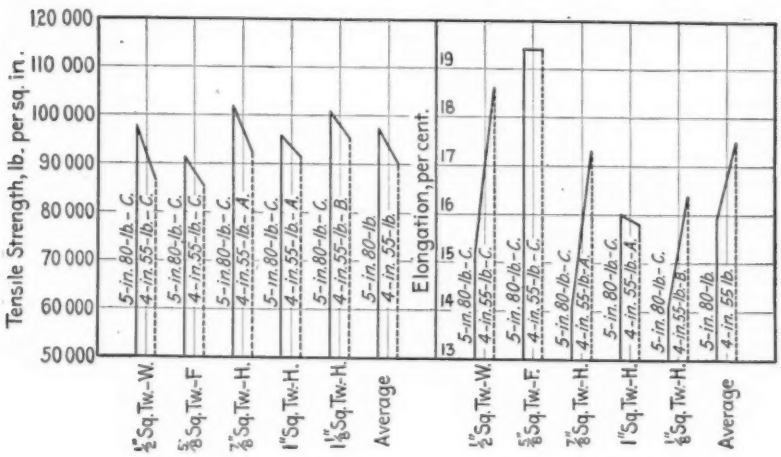


FIG. 27.—Comparison of Bars Rerolled from 55-lb. and 80-lb. Rail.

isolated and the effect determined with the fewest tests and least labor, and the least interference with the business of the mill.

Mr. P. E. Carhart, of the Illinois Steel Co., was kind enough to supply five Bessemer seconds of following composition:

Rail No.	Weight per Yard, lb.	Blow No.	Chemical Composition, per cent.		
			Carbon.	Manganese.	Sulphur.
1	75	41913-C	0.42	....	.....
2	75	41939-C	0.40	....	.....
3	75	41929-B	0.41	....	.....
4	75	41911-C	0.43	....	.....
5	75	41929-C	0.41	....	.....
6	60	43418-B	0.41	0.90	0.034
7	60	43418-B	0.41	0.90	0.034
8	60	43418-C	0.41	0.90	0.034
9	60	43409-C	0.38	0.88	0.038
10	60	43401-C	0.38	0.87	0.026

These rails were seconds, physically; each was cut into three lengths, and a short piece $1\frac{1}{2}$ ft. long. Thus each rail is represented by three pieces, 1A, 1B, 1C, about 10 ft. long, and a short piece which was used to furnish tension tests. Of the latter there are three, two from the head, and one from the flange, as shown in Fig. 28.

The head and web of the 10-ft. lengths were rolled into plain reinforcing bars at the Chicago Heights Mill of the Calumet Steel Co., and samples were cut from the bars at successive

TABLE VII.—COMPARISON OF BARS REROLLED FROM 55-LB. AND 80-LB. RAILS.

Size and Weight of Rail.	Size and Kind of Bar.	Location in Rail.	Mill.	Tensile Strength, lb. per sq. in.	Elongation, per cent.
5-in.-80-lb....	$\frac{1}{2}$-in. Sq. Tw.	Web	C	97 700	15.2
" "	$\frac{5}{8}$ " "	Flange	"	91 100	19.4
" "	$\frac{7}{8}$ " "	Head	"	101 400	14.0
" "	1 " "	"	"	95 900	16.0
" "	$1\frac{1}{8}$ " "	"	"	100 200	14.1
Average.....	.....	.....	.....	97 300	15.9
4-in.-55-lb.....	$\frac{1}{2}$-in. Sq. Tw.	Web	C	86 700	18.6
" "	$\frac{5}{8}$ " "	Flange	"	85 300	19.4
" "	$\frac{7}{8}$ " "	Head	A	92 100	17.3
" "	1 " "	"	"	91 200	15.8
" "	$1\frac{1}{8}$ " "	"	B	95 100	16.4
Average.....	.....	.....	.....	90 100	17.5

passes through the rolls. The head was reduced about six times in a cross-section and the web about eleven times.

Tables VIII and IX and Figs. 29 and 30, Plate VI, show the results of this investigation on the 75-lb. rails. Table X, Plate VI, shows the results of the tests on the 60-lb. rails. The changes between the original rail and the rerolled bar for both the 60 and 75-lb. rails are summarized in Table XI.

It is apparent that the process of rerolling has raised the mechanical quality of this material, and has brought nearer together the divergent material from the head and the flange.

VARIABILITY OF PRODUCT.

While the average material is sufficiently high in quality, it is still necessary to determine if the material is uniform. For this purpose the variability of the tests must be determined.

The extent to which varying conditions of rail supply and mill practice may operate to vary the product is shown in Table XII, where results of tests of bars from two mills, B and C, one in the middle West and one in the East, are given, to which has been added one series from mill A, in the East.

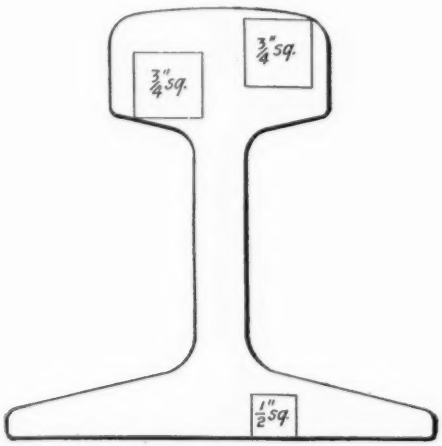


FIG. 28.

On the whole the difference between the output of mills furnishing approximately the same product is small.

In addition to this, the individual results of certain series of tests recorded in Figs. 3 to 14 (Plates I and II) have been studied, as well as the "bundle averages"; that is, the average of the tests from the bundle of ten specimens, with the result shown in Table XIII.

The variability of individual tests with respect to the average has been determined, and shown according to the standard method in Fig. 31. These curves show the percentage of the total number of tests lying between the average and any given percentage (plus or minus) of the average. Evi-



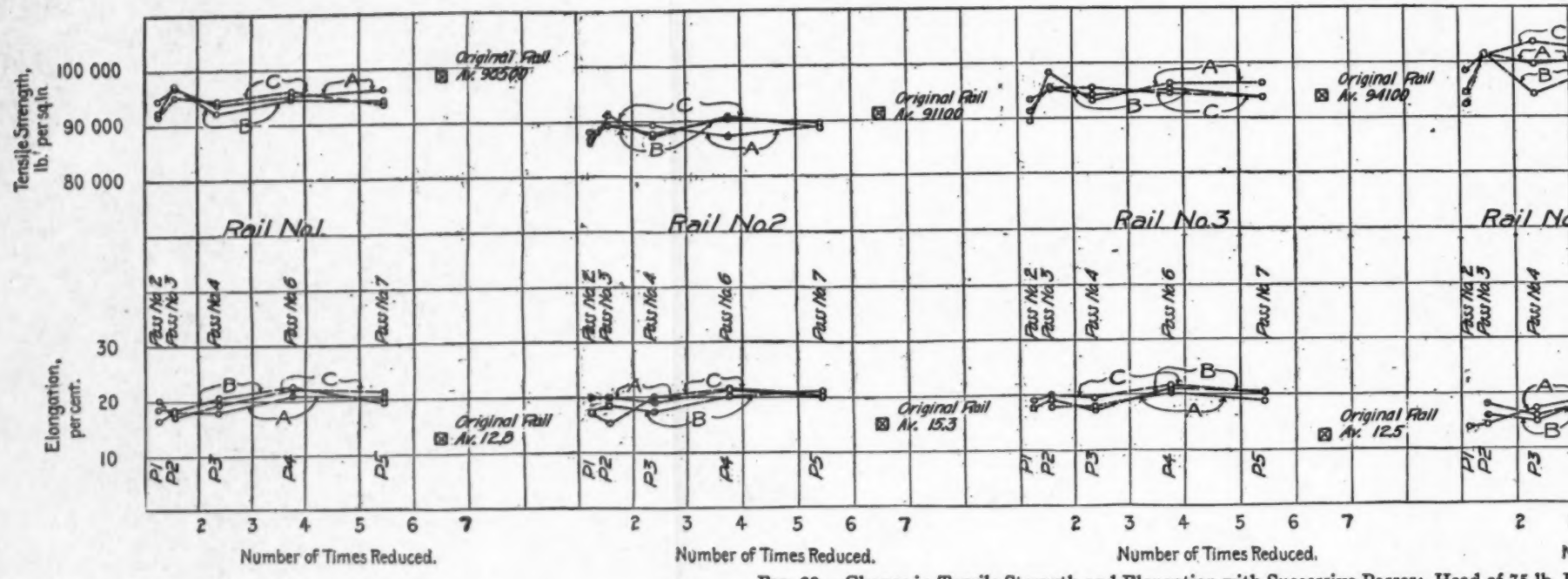
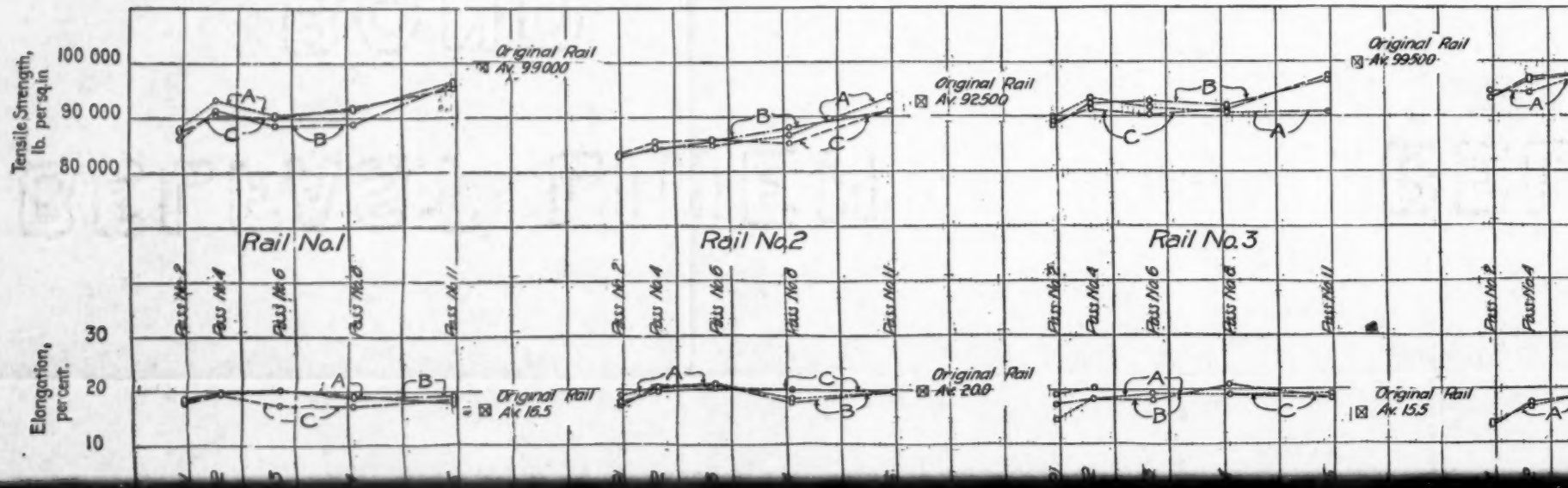
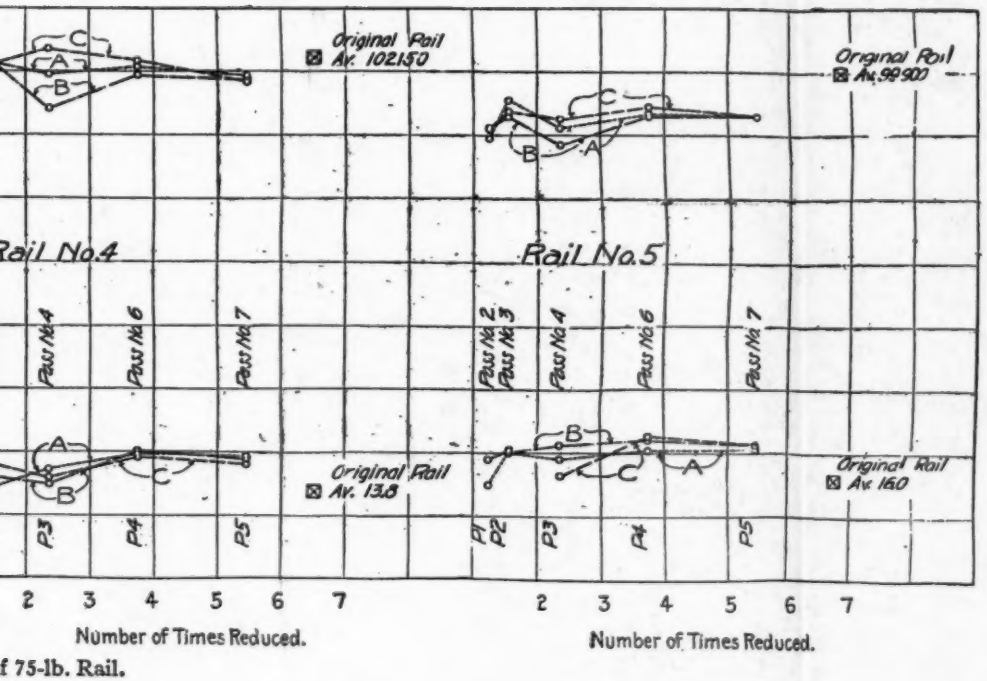


FIG. 29.—Change in Tensile Strength and Elongation with Successive Passes; Head of 75-lb. R





f 75-lb. Rail.

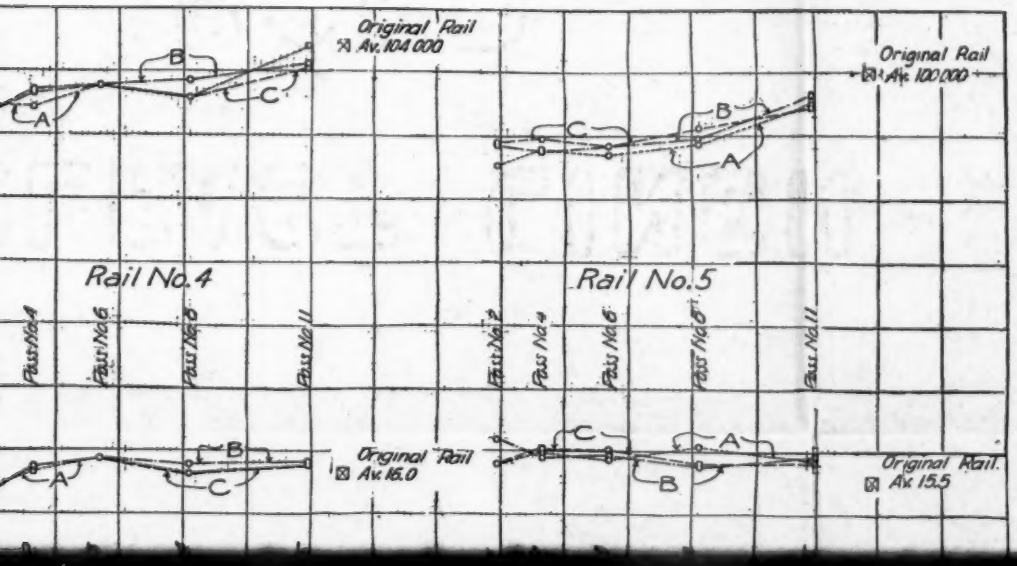


TABLE VIII.—STEEL ROLLED FROM NEW RAILS; TENSILE ST

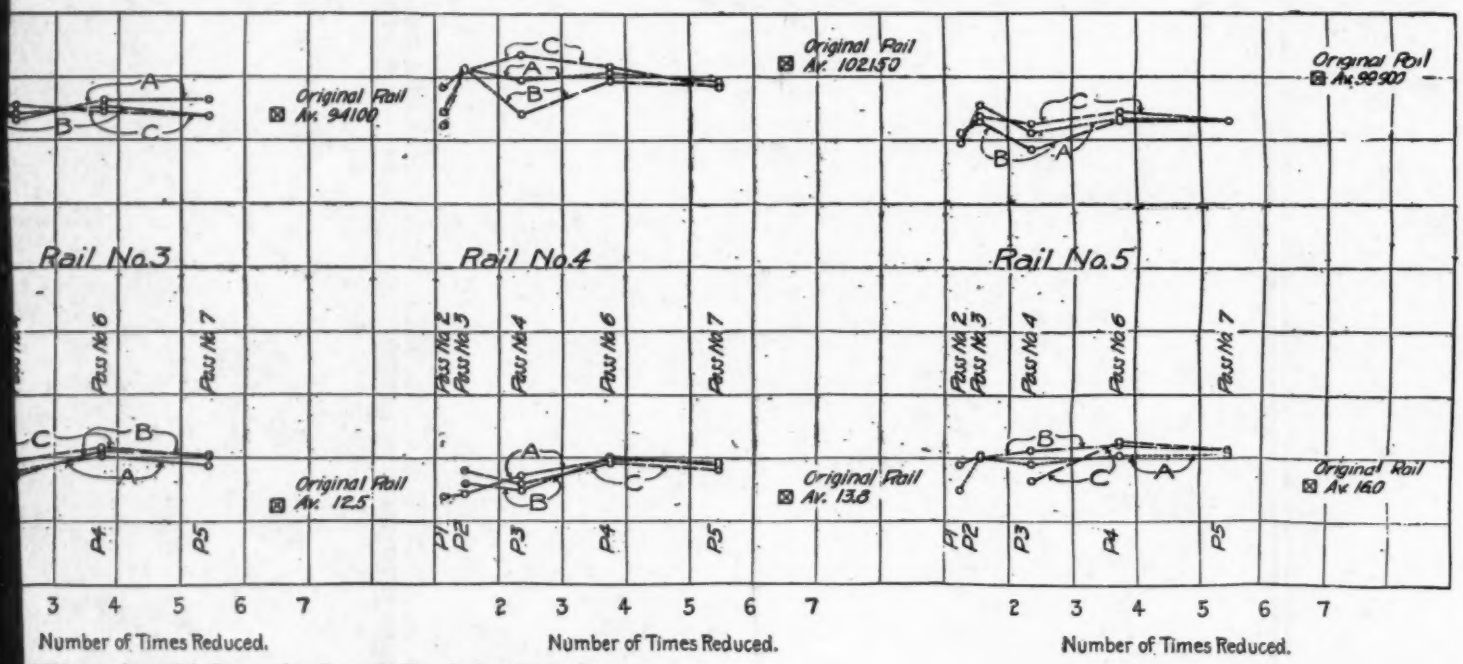
MATERIAL ROLLED FROM HEAD OF 7

Rail No.	Piece No.	Pass No. 2; reduced 2.25 times.		Pass No. 3; reduced 2.55 times.		Pass No. 4; reduced 3.35 times.		Pass No. 6; reduced 4.75 times.	
		Tensile Strength, lb. per sq. in.	Elongation, per cent.	Tensile Strength, lb. per sq. in.	Elongation, per cent.	Tensile Strength, lb. per sq. in.	Elongation, per cent.	Tensile Strength, lb. per sq. in.	Elongation, per cent.
1	A	94 700	16.5	97 000	18.25	93 850	18.0	95 050	21.0
	B	92 450	18.75	97 250	18.5	92 100	20.75	94 700	22.75
	C	91 850	20.25	95 200	17.25	94 450	19.5	96 050	22.25
	Aver.	93 000	18.5	96 480	18.0	93 470	19.4	95 270	22.0
2	A	88 000	20.0	89 400	20.0	89 400	19.0	87 250	21.5
	B	86 850	17.5	89 300	18.5	87 900	17.	90 400	20.25
	C	86 200	17.25	91 050	15.5	87 500	20.0	90 850	21.7
	Aver.	87 020	18.25	89 920	18.0	88 270	18.8	89 500	21.15
3	A	89 550	.....	98 100	18.0	93 900	18.0	96 250	20.25
	B	93 350	17.75	95 350	19.25	94 250	17.5	95 400	21.25
	C	91 300	19.0	95 600	20.0	95 700	19.7	94 500	21.75
	Aver.	91 400	18.4	96 350	19.1	94 620	18.4	95 380	21.1
4	A	92 100	14.0	101 500	14.5	99 650	17.25	100 950	19.75
	B	94 650	.....	101 400	16.0	94 100	15.0	99 400	20.0
	C	98 150	.....	101 200	18.0	103 500	16.0	101 850	19.25
	Aver.	94 970	14.0	101 370	16.2	99 080	16.1	100 730	19.7
5	A	89 550	15.0	95 550	20.0	91 100	19.0	93 450	20.5
	B	90 150	19.0	92 950	20.0	88 400	21.25	93 050	22.0
	C	91 000	19.0	93 800	20.5	92 550	16.5	94 400	22.7
	Aver.	90 230	17.7	94 100	20.2	90 680	18.9	93 630	21.7

TABLE IX.—STEEL ROLLED FROM NEW RAILS; TENSILE ST

MATERIAL ROLLED FROM WEB OF

Rail No.	Piece No.	Pass No. 2; reduced 1.9 times.		Pass No. 4; reduced 3.3 times.		Pass No. 6; reduced 5.4 times.		Pass No. 8; reduced 8.2 times.	
		Tensile Strength, lb. per sq. in.	Elongation, per cent.	Tensile Strength, lb. per sq. in.	Elongation, per cent.	Tensile Strength, lb. per sq. in.	Elongation, per cent.	Tensile Strength, lb. per sq. in.	Elongation per cent.
1	A	88 200	18.5	93 150	20.0	90 550	20.0	91 200	19.5
	B	86 150	18.75	91 350	19.75	88 600	20.25	88 950	19.0
	C	87 600	18.0	90 650	19.5	90 000	17.5	91 800	17.5
	Aver.	87 320	18.4	91 720	19.75	89 720	19.25	90 650	18.7
2	A	82 550	19.0	84 400	20.25	84 700	21.0	86 350	18.2
	B	82 800	17.25	84 100	20.5	85 550	21.0	87 850	17.5
	C	83 000	17.7	85 400	19.7	85 950	20.2	84 800	20.0
	Aver.	82 780	18.0	84 630	20.15	85 400	20.7	86 330	18.6
3	A	89 750	14.5	93 200	18.25	91 300	19.25	90 450	19.0
	B	88 800	17.25	92 300	18.25	92 650	18.0	91 750	20.7
	C	88 150	19.0	91 400	20.25	90 050	.....	90 900	19.0
	Aver.	88 900	16.9	92 300	18.9	91 330	18.6	91 030	19.6
	A	91 550	16.5	94 400	19.25	95 950	17.25	93 500	20.0
	B	93 250	13.5	97 050	7.7	97 900	19.0	98 500	18.0



d Elongation with Successive Passes; Head of 75-lb. Rail.

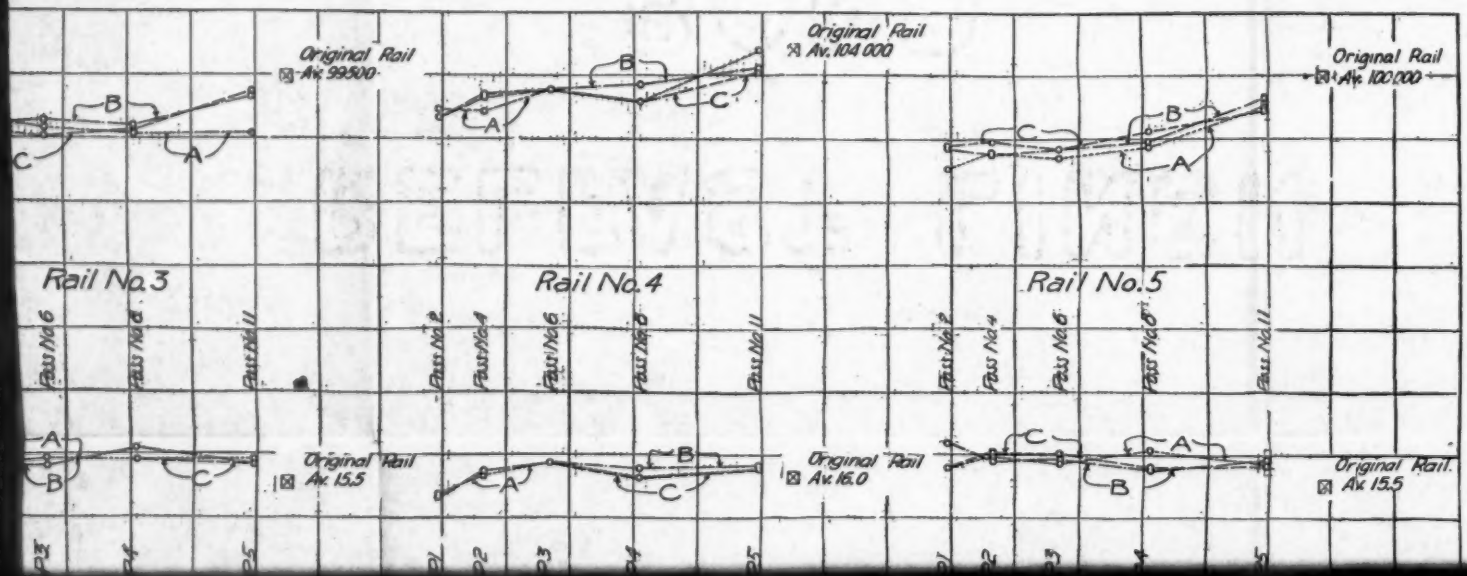


TABLE VIII.—STEEL ROLLED FROM NEW RAILS; TENSILE STRENGTH AND ELONGATION AT SUCCESSIVE PASSES.

MATERIAL ROLLED FROM HEAD OF 75-LB. BESSEMER RAIL.

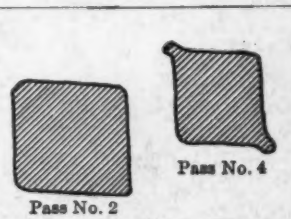
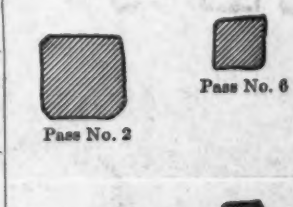
Rail No.	Piece No.	Pass No. 2; reduced 2.25 times.		Pass No. 3; reduced 2.55 times.		Pass No. 4; reduced 3.35 times.		Pass No. 6; reduced 4.75 times.		Pass No. 7; reduced 6.45 times. (Finished Bar.)		Original Rail.		Half-size Cross-sections.
		Tensile Strength, lb. per sq. in.	Elongation, per cent.	Tensile Strength, lb. per sq. in.	Elongation, per cent.	Tensile Strength, lb. per sq. in.	Elongation, per cent.	Tensile Strength, lb. per sq. in.	Elongation, per cent.	Tensile Strength, lb. per sq. in.	Elongation, per cent.	Tensile Strength, lb. per sq. in.	Elongation, per cent.	
1	A	94 700	16.5	97 000	18.25	93 850	18.0	95 050	21.0	96 400	20.1	98 500	12.8	
	B	92 450	18.75	97 250	18.5	92 100	20.75	94 700	22.75	94 200	19.6	.....	....	
	C	91 850	20.25	95 200	17.25	94 450	19.5	96 050	22.25	93 500	21.5	.....	....	
	Aver.	93 000	18.5	96 480	18.0	93 470	19.4	95 270	22.0	94 700	20.4	98 500	12.8	
2	A	88 000	20.0	89 400	20.0	89 400	19.0	87 250	21.5	90 000	20.0	.....	....	
	B	86 850	17.5	89 300	18.5	87 900	17.	90 400	20.25	89 700	21.2	.....	....	
	C	86 200	17.25	91 050	15.5	87 500	20.0	90 850	21.7	88 900	20.4	91 100	15.3	
	Aver.	87 020	18.25	89 920	18.0	88 270	18.8	89 500	21.15	86 200	20.5	91 100	15.3	
3	A	89 550	.....	98 100	18.0	93 900	18.0	96 250	20.25	96 300	18.9	94 100	12.5	
	B	93 350	17.75	95 350	19.25	94 250	17.5	95 400	21.25	93 800	20.4	.....	....	
	C	91 300	19.0	95 600	20.0	95 700	19.7	94 500	21.75	93 800	20.1	.....	....	
	Aver.	91 400	18.4	96 350	19.1	94 620	18.4	95 380	21.1	94 630	19.8	94 100	12.5	
4	A	92 100	14.0	101 500	14.5	99 650	17.25	100 950	19.75	99 200	19.5	.....	....	
	B	94 650	.....	101 400	16.0	94 100	15.0	99 400	20.0	98 800	19.1	.....	....	
	C	98 150	.....	101 200	18.0	103 500	16.0	101 850	19.25	98 400	18.1	102 150	13.8	
	Aver.	94 970	14.0	101 370	16.2	99 080	16.1	100 730	19.7	98 800	18.9	102 150	13.8	
5	A	89 550	15.0	95 550	20.0	91 100	19.0	93 450	20.5	93 200	20.7	99 900	16.0	
	B	90 150	19.0	92 950	20.0	88 400	21.25	93 050	22.0	93 100	21.4	.....	....	
	C	91 000	19.0	93 800	20.5	92 550	16.5	94 400	22.7	93 000	21.5	.....	....	
	Aver.	90 230	17.7	94 100	20.2	90 680	18.9	93 630	21.7	93 100	21.2	99 900	16.0	

TABLE IX.—STEEL ROLLED FROM NEW RAILS; TENSILE STRENGTH AND ELONGATION AT SUCCESSIVE PASSES.

MATERIAL ROLLED FROM WEB OF 75-LB. BESSEMER RAIL.

Rail No.	Piece No.	Pass No. 2; reduced 1.9 times.		Pass No. 4; reduced 3.3 times.		Pass No. 6; reduced 5.4 times.		Pass No. 8; reduced 8.2 times.		Pass No. 11; reduced 11.9 times. (Finished Bar.)		Original Rail.		Half-size Cross-sections.
		Tensile Strength, lb. per sq. in.	Elongation, per cent.	Tensile Strength, lb. per sq. in.	Elongation, per cent.	Tensile Strength, lb. per sq. in.	Elongation, per cent.	Tensile Strength, lb. per sq. in.	Elongation, per cent.	Tensile Strength, lb. per sq. in.	Elongation, per cent.	Tensile Strength, lb. per sq. in.	Elongation, per cent.	
1	A	88 200	18.5	93 150	20.0	90 550	20.0	91 200	19.5	96 600	18.0	99 000	16.5	
	B	86 150	18.75	91 350	19.75	88 600	20.25	88 950	19.0	96 100	19.3	.....	....	
	C	87 600	18.0	90 650	19.5	90 000	17.5	91 800	17.5	95 200	18.7	.....	....	
	Aver.	87 320	18.4	91 720	19.75	89 720	19.25	90 650	18.7	93 970	18.7	99 000	16.5	
2	A	82 550	19.0	84 400	20.25	84 700	21.0	86 350	18.25	93 300	19.7	.....	....	
	B	82 800	17.25	84 100	20.5	85 550	21.0	87 850	17.5	90 800	19.6	.....	....	
	C	83 000	17.7	85 400	19.7	85 950	20.2	84 800	20.0	90 600	19.6	92 500	20.0	
	Aver.	82 780	18.0	84 630	20.15	85 400	20.7	86 330	18.6	91 570	19.6	92 500	20.0	
3	A	89 750	14.5	93 200	18.25	91 300	19.25	90 450	19.0	110 500	18.3	99 500	15.5	
	B	88 800	17.25	92 300	18.25	92 650	18.0	91 750	20.75	96 600	18.4	.....	....	
	C	88 150	19.0	91 400	20.25	90 050	.....	90 900	19.0	97 100	19.0	.....	....	
	Aver.	88 900	16.9	92 300	18.9	91 330	18.6	91 030	19.6	98 070	18.6	99 500	15.5	
	A	91 550	16.5	94 400	19.25	95 950	17.25	93 500	20.0	104 000	17.4	.....	....	
	B	93 250	13.5	97 050	.7.7	97 900	19.0	98 500	18.0	101 400	18.5	.....	....	
	C	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

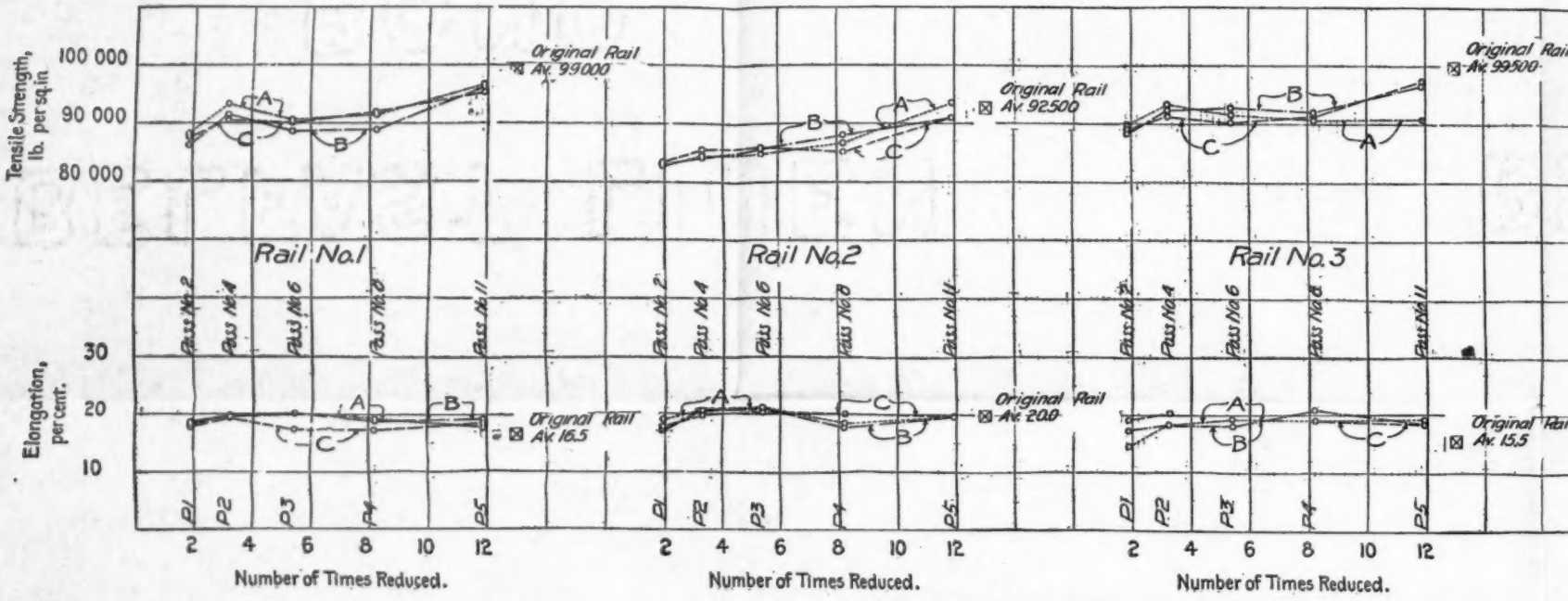
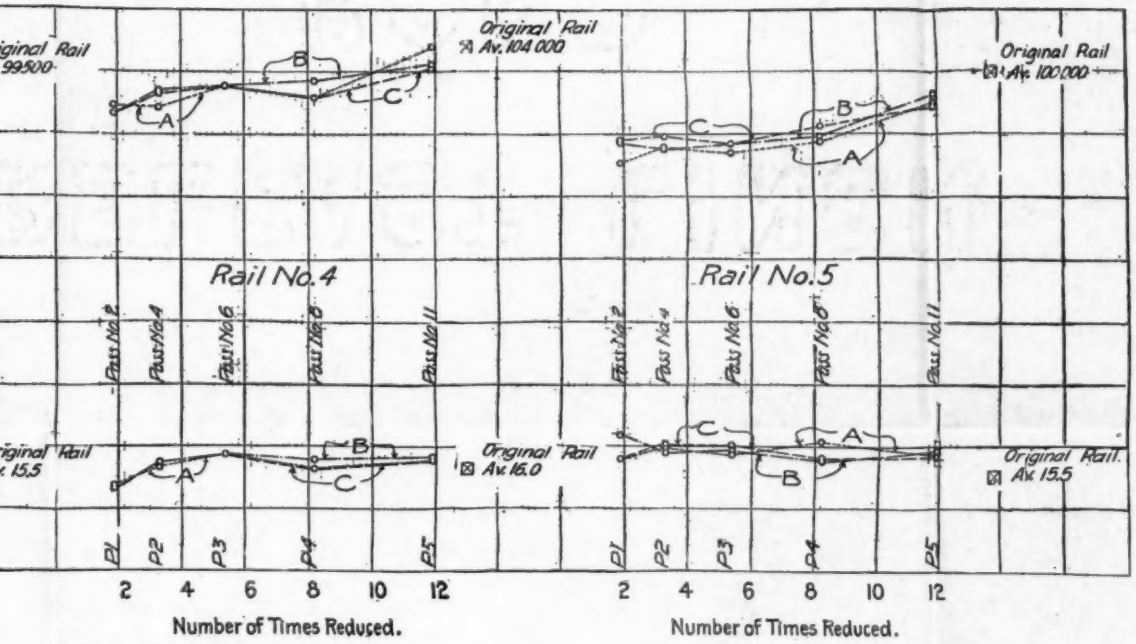


FIG. 30.—Change in Tensile Strength and Elongation with Successive Passes; W

TABLE X.—STE

Rail No.	Piece No.	Pass No. 2; reduced 1.42 times.	
		Tensile Strength, lb. per sq. in.	Elongation, per cent.
6	A	94 700	18.5
	B	97 400	17.0
	C	94 875	20.5
	Aver.	95 658	18.7
7	A	99 750	20.0
	B	97 650	19.75
	C	94 125	17.0
	Aver.	97 175	18.9
8	A	97 900	17.75
	B	93 450	16.75
	C	95 950	19.25
	Aver.	95 733	17.9
9	A	90 750	21.5
	B	87 050	21.0
	C	87 950	22.0
	Aver.	88 583	21.5
10	A	86 900	22.25
	B	91 100	23.5
	C	90 400	23.0
	Aver.	89 466	22.9



Passes; Web of 75-lb. Rail.

TABLE IX.—STEEL ROLLED FROM NEW RAILS;

MATERIAL ROLLED

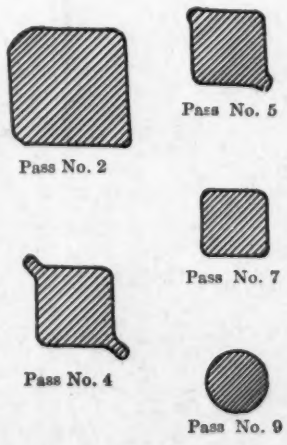
Rail No.	Piece No.	Pass No. 2; reduced 1.9 times. Tensile Strength, lb. per sq. in.	Pass No. 2; reduced 1.9 times. Elongation, per cent.	Pass No. 4; reduced 3.3 times. Tensile Strength, lb. per sq. in.	Pass No. 4; reduced 3.3 times. Elongation, per cent.	Pass No. 6; reduced 5.4 times. Tensile Strength, lb. per sq. in.	Pass No. 6; reduced 5.4 times. Elongation, per cent.
1	A	88 200	18.5	93 150	20.0	90 550	20.0
	B	86 150	18.75	91 350	19.75	88 600	20.25
	C	87 600	18.0	90 650	19.5	90 000	17.5
	Aver.	87 320	18.4	91 720	19.75	89 720	19.25
2	A	82 550	19.0	84 400	20.25	84 700	21.0
	B	82 800	17.25	84 100	20.5	85 550	21.0
	C	83 000	17.7	85 400	19.7	85 950	20.2
	Aver.	82 780	18.0	84 630	20.15	85 400	20.7
3	A	89 750	14.5	93 200	18.25	91 300	19.25
	B	88 800	17.25	92 300	18.25	92 650	18.0
	C	88 150	19.0	91 400	20.25	90 050	.....
	Aver.	88 900	16.9	92 300	18.9	91 330	18.6
4	A	91 550	16.5	94 400	19.25	95 950	17.25
	B	93 250	13.5	97 050	7.7	97 900	19.0
	C	94 500	14.0	96 750	17.0	97 800	19.0
	Aver.	93 100	14.7	96 070	18.0	97 220	18.4
5	A	85 350	18.0	87 900	19.75	87 000	19.0
	B	88 700	22.0	87 750	19.25	88 350	19.5
	C	88 900	18.0	89 550	20.5	88 500	20.5
	Aver.	87 650	19.3	88 400	19.8	87 950	19.7

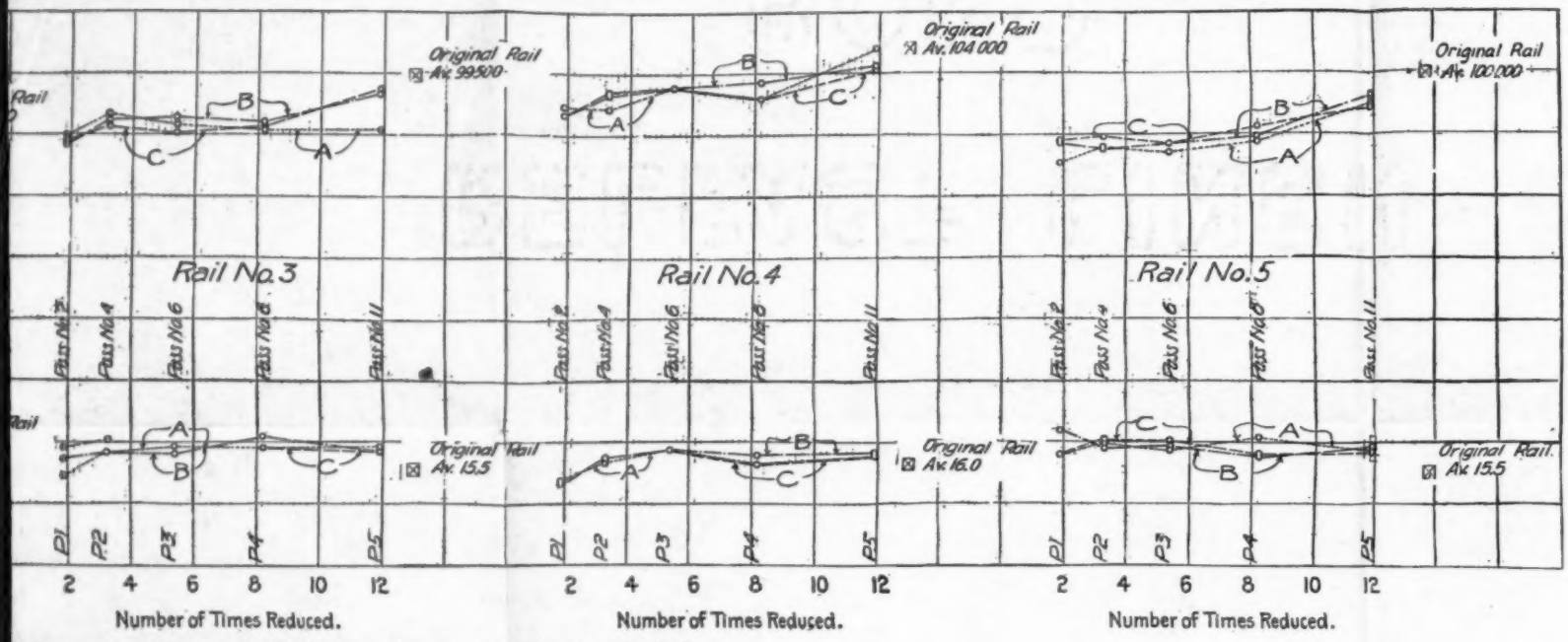
X.—STEEL ROLLED FROM NEW RAILS; TENSILE STRENGTH AND ELONGATION AT SUCCESSIVE PASSES.

MATERIAL ROLLED FROM HEAD OF 60-LB. BESSEMER RAIL.

No. 2; duced times. Elongation, per cent.	Pass No. 4; reduced 3.00 times. Tensile Strength, lb. per sq. in.	Pass No. 4; reduced 3.00 times. Elongation, per cent.	Pass No. 5; reduced 3.40 times. Tensile Strength, lb. per sq. in.	Pass No. 5; reduced 3.40 times. Elongation, per cent.	Pass No. 7; reduced 4.80 times. Tensile Strength, lb. per sq. in.	Pass No. 7; reduced 4.80 times. Elongation, per cent.	Pass No. 9; reduced 6.85 times. (Finished Bar.) Tensile Strength, lb. per sq. in.	Pass No. 9; reduced 6.85 times. (Finished Bar.) Elongation, per cent.	Original Rail. Tensile Strength, lb. per sq. in.	Original Rail. Elongation, per cent.
18.5	95 600	20.0	85 200	21.5	97 350	20.5	97 325	19.8	98 000	16.0
17.0	99 075	19.0	101 525	18.5	108 500	20.5	96 850	20.5	93 000	16.0
20.5	97 750	19.25	95 000	20.0	94 950	19.0	94 725	19.0	96 900	15.0
18.7	97 475	19.4	93 575	20.0	100 266	20.0	96 300	19.8	95 970	15.7
20.0	82 850	18.5	97 100	19.75	97 850	19.25	98 200	20.45	97 000	17.0
19.75	99 900	19.0	101 650	20.5	106 300	19.0	98 000	20.5	97 000	18.5
17.0	94 650	20.25	100 200	15.0	98 300	20.5	97 650	19.75	98 700	15.0
18.9	92 466	19.25	99 650	18.4	100 816	19.6	97 950	20.2	97 570	16.8
17.75	94 450	19.0	96 500	19.5	104 275	16.75	95 650	19.5	97 250	17.5
16.75	99 500	19.0	95 300	19.5	98 250	20.25	96 500	20.75	93 900	16.0
19.25	90 300	20.0	94 000	22.0	99 400	19.25	96 475	22.0	98 850	17.0
17.9	94 750	19.3	95 266	20.3	100 642	18.75	96 208	20.75	96 660	16.8
21.5	94 600	18.5	100 100	22.0	98 950	20.25	92 650	20.25	91 500	19.5
21.0	92 125	21.25	84 500	18.5	94 100	21.25	92 000	22.5	86 500	17.5
22.0	87 250	20.25	92 550	22.75	88 375	21.25	91 700	21.5	90 600	17.5
21.5	91 325	20.0	92 380	21.1	93 808	20.9	92 116	21.4	89 530	18.2
22.25	84 825	19.25	94 925	22.5	96 000	22.0	92 150	20.75	92 200	20.5
23.5	87 725	23.25	96 900	15.5	83 125	21.75	92 150	21.0	88 800	15.5
23.0	95 650	22.75	89 100	22.0	90 550	22.5	92 000	21.0	91 700	20.0
22.9	89 400	21.8	93 642	20.0	89 891	22.1	92 100	20.9	90 900	18.7

Half-size Cross-sections.



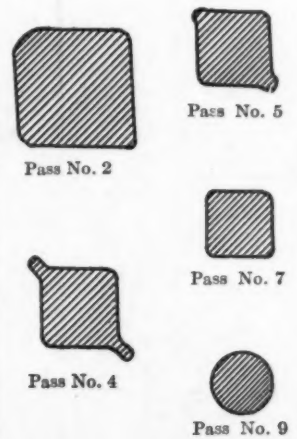


le Strength and Elongation with Successive Passes; Web of 75-lb. Rail.

TABLE X.—STEEL ROLLED FROM NEW RAILS; TENSILE STRENGTH AND ELONGATION AT SUCCESSIVE PASSES.

MATERIAL ROLLED FROM HEAD OF 60-LB. BESSEMER RAIL.

Rail No.	Piece No.	Pass No. 2; reduced 1.42 times.		Pass No. 4; reduced 3.00 times.		Pass No. 5; reduced 3.40 times.		Pass No. 7; reduced 4.80 times.		Pass No. 9; reduced 6.85 times. (Finished Bar.)		Original Rail.		Half-size Cross-sections.
		Tensile Strength, lb. per sq. in.	Elongation, per cent.	Tensile Strength, lb. per sq. in.	Elongation, per cent.	Tensile Strength, lb. per sq. in.	Elongation, per cent.	Tensile Strength, lb. per sq. in.	Elongation, per cent.	Tensile Strength, lb. per sq. in.	Elongation, per cent.	Tensile Strength, lb. per sq. in.	Elongation, per cent.	
6	A	94 700	18.5	95 600	20.0	85 200	21.5	97 350	20.5	97 325	19.8	98 000	16.0	
	B	97 400	17.0	99 075	19.0	101 525	18.5	108 500	20.5	96 850	20.5	93 000	16.0	
	C	94 875	20.5	97 750	19.25	95 000	20.0	94 950	19.0	94 725	19.0	96 900	15.0	
	Aver.	95 658	18.7	97 475	19.4	93 575	20.0	100 266	20.0	96 300	19.8	95 970	15.7	
7	A	99 750	20.0	82 850	18.5	97 100	19.75	97 850	19.25	98 200	20.45	97 000	17.0	
	B	97 650	19.75	99 900	19.0	101 650	20.5	106 300	19.0	98 000	20.5	97 000	18.5	
	C	94 125	17.0	94 650	20.25	100 200	15.0	98 300	20.5	97 650	19.75	98 700	15.0	
	Aver.	97 175	18.9	92 466	19.25	99 650	18.4	100 816	19.6	97 950	20.2	97 570	16.8	
8	A	97 900	17.75	94 450	19.0	96 500	19.5	104 275	16.75	95 650	19.5	97 250	17.5	
	B	93 450	16.75	99 500	19.0	95 300	19.5	98 250	20.25	96 500	20.75	93 900	16.0	
	C	95 950	19.25	90 300	20.0	94 000	22.0	99 400	19.25	96 475	22.0	98 850	17.0	
	Aver.	95 733	17.9	94 750	19.3	95 266	20.3	100 642	18.75	96 208	20.75	96 660	16.8	
9	A	90 750	21.5	94 600	18.5	100 100	22.0	98 950	20.25	92 650	20.25	91 500	19.5	
	B	87 050	21.0	92 125	21.25	84 500	18.5	94 100	21.25	92 000	22.5	86 500	17.5	
	C	87 950	22.0	87 250	20.25	92 550	22.75	88 375	21.25	91 700	21.5	90 600	17.5	
	Aver.	88 583	21.5	91 325	20.0	92 380	21.1	93 808	20.9	92 116	21.4	89 530	18.2	
10	A	86 900	22.25	84 825	19.25	94 925	22.5	96 000	22.0	92 150	20.75	92 200	20.5	
	B	91 100	23.5	87 725	23.25	96 900	15.5	83 125	21.75	92 150	21.0	88 800	15.5	
	C	90 400	23.0	95 650	22.75	89 100	22.0	90 550	22.5	92 000	21.0	91 700	20.0	
	Aver.	89 466	22.9	89 400	21.8	93 642	20.0	89 891	22.1	92 100	20.9	90 900	18.7	



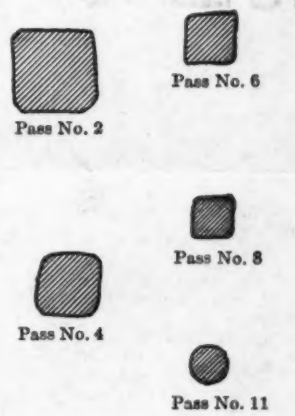
TABL

Rail No.	Piece No.	Pa 1
		Ten Stre lb. sq.
1	A	88
	B	86
	C	87
	Aver.	87
2	A	82
	B	82
	C	83
	Aver.	82
3	A	89
	B	88
	C	88
	Aver.	88
4	A	91
	B	93
	C	94
	Aver.	93
5	A	85
	B	88
	C	88
	Aver.	87

TABLE IX.—STEEL ROLLED FROM NEW RAILS; TENSILE STRENGTH AND ELONGATION AT SUCCESSIVE PASSES.

MATERIAL ROLLED FROM WEB OF 75-LB. BESSEMER RAIL.

Piece No.	Pass No. 2; reduced 1.9 times.		Pass No. 4; reduced 3.3 times.		Pass No. 6; reduced 5.4 times.		Pass No. 8; reduced 8.2 times.		Pass No. 11; reduced 11.9 times. (Finished Bar.)		Original Rail.		Half-size Cross-sections.
	Tensile Strength, lb. per sq. in.	Elongation, per cent.	Tensile Strength, lb. per sq. in.	Elongation, per cent.	Tensile Strength, lb. per sq. in.	Elongation, per cent.	Tensile Strength, lb. per sq. in.	Elongation, per cent.	Tensile Strength, lb. per sq. in.	Elongation, per cent.	Tensile Strength, lb. per sq. in.	Elongation, per cent.	
A	88 200	18.5	93 150	20.0	90 550	20.0	91 200	19.5	96 600	18.0	99 000	16.5	
B	86 150	18.75	91 350	19.75	88 600	20.25	88 950	19.0	96 100	19.3	.....	....	
C	87 600	18.0	90 650	19.5	90 000	17.5	91 800	17.5	95 200	18.7	.....	....	
Aver.	87 320	18.4	91 720	19.75	89 720	19.25	90 650	18.7	95 970	18.7	99 000	16.5	
A	82 550	19.0	84 400	20.25	84 700	21.0	86 350	18.25	93 300	19.7	.....	....	
B	82 800	17.25	84 100	20.5	85 550	21.0	87 850	17.5	90 800	19.6	.....	....	
C	83 000	17.7	85 400	19.7	85 950	20.2	84 800	20.0	90 600	19.6	92 500	20.0	
Aver.	82 780	18.0	84 630	20.15	85 400	20.7	86 330	18.6	91 570	19.6	92 500	20.0	
A	89 750	14.5	93 200	18.25	91 300	19.25	90 450	19.0	100 500	18.3	99 500	15.5	
B	88 800	17.25	92 300	18.25	92 650	18.0	91 750	20.75	96 600	18.4	.....	....	
C	88 150	19.0	91 400	20.25	90 050	.....	90 900	19.0	97 100	19.0	.....	....	
Aver.	88 900	16.9	92 300	18.9	91 330	18.6	91 030	19.6	98 070	18.6	99 500	15.5	
A	91 550	16.5	94 400	19.25	95 950	17.25	93 500	20.0	104 000	17.4	.....	....	
B	93 250	13.5	97 050	7.7	97 900	19.0	98 500	18.0	101 400	18.5	.....	....	
C	94 500	14.0	96 750	17.0	97 800	19.0	96 000	16.5	100 700	18.0	104 000	16.0	
Aver.	93 100	14.7	96 070	18.0	97 220	18.4	96 000	18.2	102 030	18.0	104 000	16.0	
A	85 350	18.0	87 900	19.75	87 000	19.0	88 700	21.0	95 000	18.9	100 000	15.5	
B	88 700	22.0	87 750	19.25	88 350	19.5	90 650	18.0	96 300	19.7	.....	....	
C	88 900	18.0	89 550	20.5	88 500	20.5	91 100	18.2	94 600	18.6	.....	....	
Aver.	87 650	19.3	88 400	19.8	87 950	19.7	90 150	19.1	95 300	19.1	100 000	15.5	



dently the four series examined show a regular variation and the material is not erratic. The individual series upon which Fig. 31 is based are shown in Fig. 32.

TABLE XI.—SUMMARY SHOWING EFFECT OF REROLLING.

75-LB. RAIL.

Position in Rail.	Properties Considered.	Original Rail.	Rerolled Rail.
Head[1]	Tensile Strength, lb. per sq. in.	97 150	93 480
	Elongation, per cent.	14.80	20.16
	Product.	1 370 000	1 890 000
Flange	Tensile Strength, lb. per sq. in.	99 000	96 580
	Elongation, per cent.	16.70	19.20
	Product.	1 650 000	1 850 000

60-LB. RAIL.[2]

Head	Tensile Strength, lb. per sq. in.	94 130	94 940
	Elongation, per cent.	17.2	20.6
	Product.	1 619 000	1 955 760

[1] Abstract from Table VIII.
[2] Abstract from Table X.

Ninety per cent of the tests lie within a variation of 15 per cent (plus or minus) of the average and the remaining 10 per cent exhibit an increasing variability up to 30 per cent.

TABLE XII.—COMPARISON OF TESTS ON BARS FROM DIFFERENT MILLS.

MATERIAL FROM FLANGE.

Mill.	Size and Kind of Bar.	Tensile Strength, lb. per sq. in.	Elongation, per cent.
B	$\frac{5}{8}$-in. Def. Rd.	101 650	16.4
C	$\frac{5}{8}$-in. Pl. Rd.	101 420	17.7
	MATERIAL FROM HEAD.		
B	$1\frac{1}{8}$-in. Sq. Tw.	95 000	17.0
C	$1\frac{1}{8}$ " "	99 500	19.0
A	$\frac{3}{4}$-1 " "	93 600	17.4
C	$\frac{3}{4}$ " "	92 600	18.0

This variability is based upon a sufficient number of tests, and it may be assumed that the maximum and minimum values have been determined. To judge of the significance of the variability, this range should be compared with the range of other classes of steel with which we have had experience, and for which rules are fixed.

Discussion of Variability.—The writer has not had access to any series of tests comparable to these, from which he might derive similar data of variability. A range of individual bars from +12 per cent to −12 per cent of the average corresponds

TABLE XIII.—REROLLED RAIL STEEL; APPROXIMATE VARIABILITY FACTORS.

Size and Kind of Bar.	Mill.	Tensile Strength.			Yield Point.
		Percentage of Bars from +12% to −12% of Average.	Percentage Range of Bundle Averages from Whole Average.	Percentage Range of Single Values, Max. to Min.	Percentage Range of Bundle Averages from Whole Average.
$\frac{7}{8}$-1-in. Tw.....	A	83.1	18.4	58.6	21.2
$\frac{9}{16}$-in. Def. Rd....	B	66.5	14.8	52.8	9.2
$\frac{1}{2}$ " Tw.....	C	69.0	18.3	51.2	....
$\frac{5}{8}$ " Pl.....	D	82.8	15.8	49.3	12.9
$\frac{5}{8}$ " Def. Sq..	E	94.8	8.3	39.0	8.3
$\frac{7}{8}$ " Def. Sq..	E	73.8	6.0	47.4	....
$\frac{3}{8}$ " Pl.....	E	75.8	19.7	45.0	....

to the specification limits of from 55,000 to 70,000 lb. per sq. in. set for the tensile strength of structural-steel reinforcing bars. It will be seen that, on the average, 80 per cent of the rerolled bars lie within this range. The variability of the yield point is nearly of the same degree as that of the tensile strength.

The variability of high-carbon billet steel used for reinforcing bars should be known for comparison with the writer's tests, but no data are available to the writer.

One important application of the variability data is in fixing a lot for test, that is, the number of tons represented by a sample bar. The present specifications for high-carbon billet reinforcing bars fix one test per ten-ton lot. In the case of

rerolled rail steel, the variation in the carbon content of rails of varying section should be recognized. Inasmuch as the rerolling mills must fix their rolls for a rail of given width of base, any run of the mill must include rails of nearly the same section; so that, in fixing a lot for testing, the variation in the quality of steel from rails of varying size will be met by specifying that the lot to be sampled shall be rolled from rails differing not more than 10 lb. nominal weight of section. On this basis a lot of the size equal to that specified for high-carbon billet steel may be used.

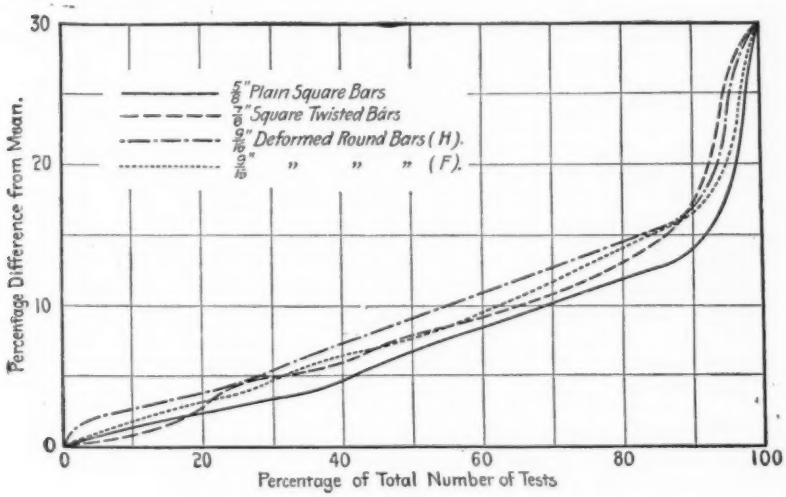


FIG. 31.—Percentage of Total Number of Tests lying within any given Percentage of the Mean Tensile Strength.

Some facts of reinforced concrete building construction will be useful in judging of the variability to be allowed in reinforcing steel. A reinforced concrete unit, such as a beam, slab or column, employs a number of bars. Thus, in a band of bars in a flat slab there may be as many as 20 bars, of small size, below $\frac{3}{4}$ in.; in an ordinary one-way slab, as many as 12 bars in a width that acts integrally; in a column, 4 to 20 bars; in a beam, 5 to 12 bars; in a footing, more than 25 bars. It should be recollected that the tendency in reinforced concrete building construction is toward flat slabs, and spiral columns,

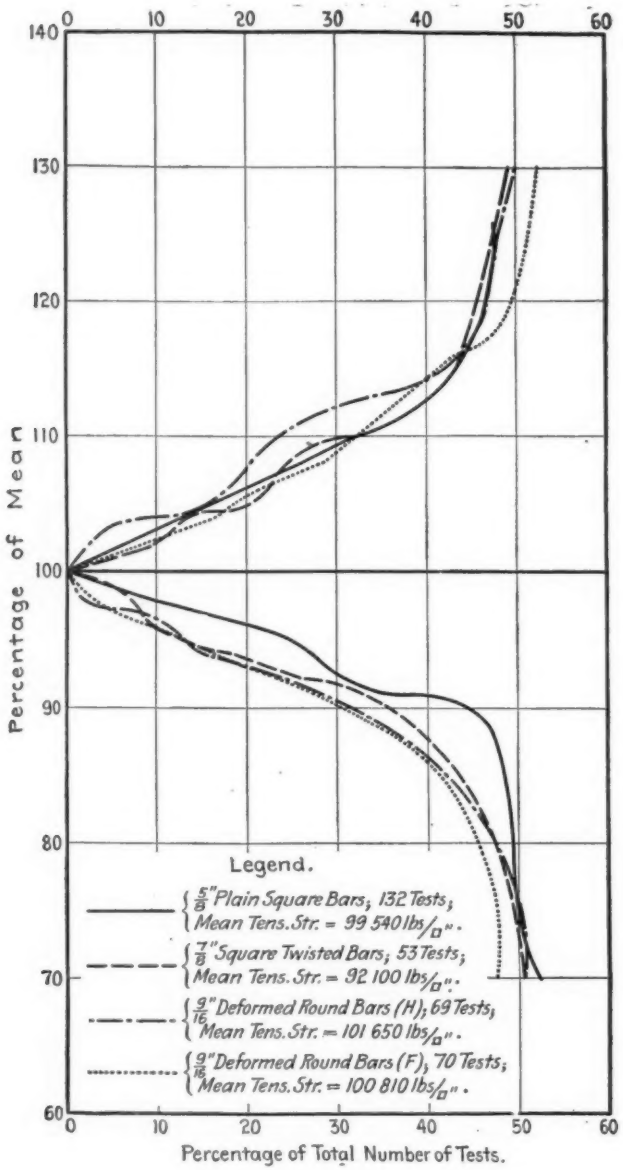


FIG. 32.—Percentage of Total Number of Tests lying between the Mean and any given Percentage of the Mean.

TABLE XIV.—COMPARISON WITH REQUIREMENTS OF PRESENT SPECIFICATIONS; PERCENTAGE OF BARS THAT DID NOT PASS—SINGLE CASES.

Size	3/8 in.	1/2 in.		9/16 in.			5/8 in.					3/4 in.			7/8 in.				1 in.			1 1/8 in.		1 1/4 in.	
Shape	Pl. Rd.	Sq. Tw.	Sq. Tw.	C. Rd.	C. Rd.	Pl. Rd.	C. Rd.	Pl. Rd.	Sq. Tw.	Pl. Sq.	C. Sq.	Sq. Tw.	Sq. Tw.	Pl. Rd.	Sq. Tw.	Sq. Tw.	Pl. Rd.	C. Sq.	Sq. Tw.	Sq. Tw.	Pl. Rd.	Sq. Tw.	Sq. Tw.	Sq. Tw.	Sq. Tw.
Mill	E	B	C	B		C	B	C		D	E	A	C		A	C		E	A	C		B	C	B	C
Source	W	H	W	F	H	W	F	F	F	H	F	H	H	F	H	H	H	H	H	H	H	H	H	H	H
Bend	0	1	7	1	1	0	2	0	1	3	3	6	0	0	12	10	0	13	18	18	5	10	20	20	10
Tensile Strength	2	0	9	1	1	0	0	0	7	2	2	0	5	0	8	0	0	4	18	0	0	..	0	10	20
Yield Point	0	0	0	0	0	0	0	0	3	0	0	0	5	0	9	0	0	2	14	2	0	..	0	5	22
Elongation	0	0	3	1	0	0	2	0	1	5	2	0	0	0	11	6	0	3	10	15	5	5	0	0	5
All Specifications	2	0	20	3	2	0	4	0	8	8	5	6	6	0	25	14	0	17	43	25	10	..	..	..	..
No. of Bars—Bend Test	62	100	70	69	70	20	50	26	70	140	60	32	20	20	100	10	10	60	50	40	20	20	20	19	20
No. of Bars—Tension Test	62	95	69	71	70	19	48	20	55	132	57	27	18	20	63	7	10	57	28	20	20	9	7	3	18
No. of Burned Bars	.....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	0	10	0	9

W—Web. H—Head. F—Flange.

all of which use small rods. The nature of concrete is to spread loads, and average up physical conditions. It would appear that a greater variability of product is therefore admissible than in other steel structures, where a structural unit comprehends a few bars.

Bars in concrete are protected from sharp impacts and sudden loads, and do not need the same toughness as in other structures. Nor are they subjected to the shop processes that demand a tough material. Large concrete bars are, however, usually bent with a maximum bend of 45 deg., small bars to 90 deg. and at times to 180 deg. Here a certain toughness is required, and the bars receive effective field test when

TABLE XV.—TABLE SHOWING ACCEPTANCES UNDER PRESENT SPECIFICATIONS (AVERAGE OF TABLE XIV).

Kind.	Size of Bar.	Percentage of Number of Bars passing.				
		Bend.	Tensile Strength.	Yield Point.	Elongation.	All Tests.
Twisted Bars.	All.....	92.1	94.1	95.9	95.0	83.4
	1 in. and below....	92.0	94.6	96.4	95.0	84.0
	$\frac{3}{4}$ in. and below ..	97.0	96.0	98.7	99.3	92.0
Other Bars.	All.....	97.2	99.0	.....	98.2	95.1
	1 in. and below....	98.0	99.0	98.2	98.3	95.7
	$\frac{3}{4}$ in. and below...	99.0	99.2	100.0	99.0	97.0

they are bent. In Europe it is common to give short bends for anchorage, and in this country for stirrups. Difficult bends on large bars should not be made cold.

APPLICATION OF PRESENT SPECIFICATION TO RESULTS OF TESTS.

In order to intelligently prepare a specification, the results of its application to the product should be determined.

The present specifications of the American Society for Testing Materials for reinforcing bars of hard grade have been applied to these tests. The hot-twisted billet-steel bars were classed as deformed bars.

The results of the present application will be more severe than in practice because, first, some bars were tested that would

be rejected on inspection; and second, none of the deformed bars were planed to uniform section.

Table XIV shows the results of this application, which are summarized in Table XV. It is evident that not enough samples were collected of material beyond 1 in. in diameter, and moreover the $1\frac{1}{4}$ and $1\frac{1}{8}$-in. bars from mill C represent material that would have been rejected upon surface inspection, so that the results of bars 1 in. and below would be more significant of the facts than the entire series of tests. In drawing general conclusions it is necessary to separate those bars above 1 in. in diameter. Whether plain bars of this size would be any better is not known, because none were collected. However, the indications are that the twisted bars are inferior to the others. It should be stated, however, that the difficulty of rerolling good material will increase with the size of bar for the reason that there will not be enough reduction from the head of the rail to the finished bar, and any flaw or segregations in the head of the original rail are not so likely to be effaced in the rolls.

It is difficult to find rails of sufficiently large head to roll such large bars as $1\frac{1}{8}$ and $1\frac{1}{4}$ in. The proportion of the product rolled in these sizes is small.

It will be noticed that the twisted bars fail more often under the bend test than under the other forms of test. This is probably due partly to the fact that those tension bars which broke outside the gage length are not included in the tension test averages.

[For discussion of this investigation, see pp. 169–174.—ED.]

APPENDIX III.

REPORT OF THE INVESTIGATION OF WROUGHT STEEL WHEELS

CONDUCTED UNDER THE DIRECTION OF SUB-COMMITTEE VII, ON ROLLED STEEL WHEELS AND STEEL TIRES, OF COMMITTEE A-1.

PHILADELPHIA, January 30, 1913.

MR. A. A. STEVENSON, *Chairman*,

Sub-Committee VII, Committee A-1, A. S. T. M.,

Morris Building, Philadelphia, Pa.

Dear Sir:

Under date of March 1, 1912, you appointed the following as a Sub-Committee on Investigation of Wrought Steel Wheels:

G. Aertsen, The Midvale Steel Co., Chairman.
C. D. Young, Engineer of Tests, The Pennsylvania Railroad Co.;
C. F. W. Rys, Metallurgist, Carnegie Steel Co.;
C. S. Churchill, Chief Engineer, Norfolk & Western Railway Co.

To this sub-committee was added, subsequently:

Mr. H. A. Benedict, Mechanical Engineer, Public Service Railway Co., Newark, N. J.

The sub-committee was to consider the following questions:

1. Mating and grouping;
2. Analyses;
3. Thermal tests;
4. Drop tests.

Meetings were held May 28, 1912, at Philadelphia, and July 30, August 8, 9 and 10, October 1 and 2, 1912, at Altoona.

The tests referred to in this report may be described in detail as follows:

The M. C. B. Standard Thermal Test is that described by the M. C. B. Specifications for Cast-Iron Wheels, the ring of molten cast iron being $1\frac{1}{2}$ in. thick, removed from the tread of the wheel promptly after setting, say $2\frac{1}{2}$ to $3\frac{1}{2}$ minutes after pouring is stopped.

The Double Thermal Quench Test is the same as above, except that the ring of molten cast iron is 3 in. thick, allowed to set from 4 to $4\frac{3}{4}$ minutes after pouring, the wheel being then immersed in water about $1\frac{1}{4}$ to $2\frac{1}{4}$ minutes after the removal of the cast-iron ring and left in the water from $4\frac{3}{4}$ to 6 minutes, or until cold.

The M. C. B. Standard Drop Test is that provided by the M. C. B. Specifications for Cast-Iron Wheels and consists in supporting the wheel at three points under the back of the rim and striking the front projection of the hub 12 blows with a 200-lb. tup falling 12 ft.

The Destruction Test was made under the axle drop at the Juniata Shops of The Pennsylvania Railroad Co., the wheel lying on its back supported at three points under the back of the rim. On the front projection of the hub was placed a "peg" consisting of a piece of steel about 10 in. in diameter, 10 in. high, weighing about 200 lb. This was used to insure the hub projection being struck a fair blow by the hammer-face of the falling tup, which weighed 1640 lb. The first blow was delivered from a height of 5 ft., the next 10 ft., the next 15 ft., and the next 20 ft.

During the thermal test the streams of molten cast iron cut the flange of each wheel where they struck during pouring. As no signs of other damage were visible, the examinations of the wheels after the thermal tests were reported as "O. K."

The following tests were made:

The Pennsylvania Railroad Co. procured 8 wheels, two from each of the four American manufacturers. Each wheel was analyzed before testing, drillings being taken from two points 90 deg. apart on the same circumference about 3 in. inside the rim. Drillings were not mixed, but a part of each sample was

TABLE I.—RESULTS OF TESTS.

Kind of Test.	Wheel. A	B	C	D	E	F	G	H
M. C. B. DROP.								
Number of Blows.....	12	12	12	12	....	....	....	....
Inspection.....	O. K.	O. K.	O. K.	O. K.	....	....	....	....
Number of Blows.....	18	18	18	18	....	....	....	....
Inspection.....	O. K.	O. K.	O. K.	O. K.	....	....	....	....
THERMAL[1].....	....	....	....	....	Normal	Normal	Normal	Normal
Inspection.....	....	....	....	....	O. K.	O. K.	O. K.	O. K.
DOUBLE THERMAL AND QUENCH[1].....	....	....	....	....	....	....	....	....
Inspection.....	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.
M. C. B. DROP.								
Number of Blows.....	12	12	12	12	12	12	12	12
Inspection.....	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.
1640-LB. DROP.								
Deflection, in., after one blow each at:								
5 ft..... Hub	None	None	None	Broke	1/32	None	None	None
5 ft..... Rim	None	None	None	....	None	None	None	None
10 ft..... Hub	1/32	1/32	1/32	....	Broke	1/64	1/16	1/32
10 ft..... Rim	None	None	1/32	....	....	None	1/32	1/32
15 ft..... Hub	1/32	Broke	Broke	....	....	1/32	Broke	1/8
15 ft..... Rim	1/32	....	....	....	....	None	....	1/32
20 ft..... Hub	Broke	....	....	....	....	Broke	....	3/16
20 ft..... Rim	....	....	....	....	....	....	....	1/16

DESCRIPTION OF WHEELS AFTER DESTRUCTION.

A.—Hub punched out. Rim intact. Plate shattered. No sign of previous fracture.

B.—Broke through rim on both sides about 150 deg. apart, crack extending around plate through punched hole and leaving hub attached to other side of plate. No sign of previous fracture.

C.—Hub punched out. Rim intact. No sign of previous fracture.

D.—Hub punched out. Rim intact. No sign of previous fracture.

E.—Hub punched out and plate shattered. Rim intact. No sign of previous fracture.

F.—Broke all around plate. Rim intact. No sign of previous fracture.

G.—Hub punched out. Rim intact. No sign of previous fracture.

H.—After blow at 10 ft. there was indication of crack in flange where cast iron had struck it in pouring, which crack, after blow at 20 ft., extended through rim on other side and part way around plate. Test stopped at this point.

[1] For description of Thermal and Double Thermal and Quench Tests, see report.

sent to the manufacturer of the wheel represented for checking purposes.

One wheel of each pair was subjected to the M. C. B. standard thermal test. The wheel was allowed to become cold and then examined for surface imperfections. It was then subjected to the double thermal and quenching test, examined for surface imperfections, and subjected to the M. C. B. standard drop test. It was then examined for surface imperfections and tested to destruction with the 1640-lb. drop.

The second wheel of each pair was subjected to the M. C. B. standard drop test. It was then examined for surface imperfections and subjected to 18 additional blows from the M. C. B. standard drop (200 lb. falling 12 ft.). It was then examined

TABLE II.—CHEMICAL ANALYSES.

Wheel.	Chemical Composition, per cent.							
	C	Mn	P	Si	S	Ni	Cr	Cu
A.....	0.699	0.624	0.037	0.249	0.038	0.116	0.025	0.100
B.....	0.682	0.689	0.039	0.278	0.030	0.259	0.033	0.095
C.....	0.803	0.586	0.016	0.181	0.026	0.031	0.017	.....
D.....	0.717	0.750	0.021	0.209	0.033	0.038	0.037	.....
E.....	0.714	0.730	0.024	0.194	0.034	0.045	0.037	.....
F.....	0.681	0.663	0.034	0.292	0.045	0.132	0.016	0.135
G.....	0.734	0.708	0.030	0.163	0.028	0.047	0.015	.....
H.....	0.693	0.692	0.040	0.271	0.031	0.284	0.027	0.085

for surface imperfections and subjected to the double thermal test and quenched. It was then subjected to the M. C. B. standard drop test, examined for surface imperfections, and tested to destruction with the 1640-lb. drop.

Tabulated results of these tests, together with the chemical analyses, are given in Tables I and II.

The committee is unable to offer final recommendations upon the four points under consideration, but can only report progress as follows:

1. *Mating and Grouping.*—Large numbers of wheels have been mated and grouped by carbon and put into service by different consumers. Until results of these trials are obtained the committee can make no recommendations.

2. *Analyses.*—The remark under No. 1 applies here also.

3. *Thermal Tests.*—The effect of this test upon rolled steel wheels seems imperceptible. The committee does not recommend its incorporation in a specification.

4. *Drop Test.*—Information thus far obtained by the committee does not seem to justify the recommendation of any test to be applied to groups or individual wheels. The committee can only report progress under this head.

Respectfully submitted,

G. AERTSEN,
Chairman.

AMERICAN SOCIETY FOR TESTING MATERIALS

PHILADELPHIA, PA., U. S. A.

AFFILIATED WITH THE

INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

STANDARD SPECIFICATIONS FOR MEDIUM-CARBON STEEL SPLICE BARS.

ADOPTED AUGUST 25, 1913.

I. MANUFACTURE.

1. The steel shall be made by the open-hearth process. **Process.**

2. (*a*) The splice bars may be punched, slotted and, in the case of special designs, shaped either hot or cold. **Finishing.**

(*b*) Bars that are punched, slotted or shaped cold shall be subsequently annealed.

II. CHEMICAL PROPERTIES AND TESTS.

3. The steel shall conform to the following requirements as to chemical composition: **Chemical Composition.**

Carbon	not under	0.30 per cent
Phosphorus	not over	0.04 "

4. An analysis to determine the percentages of carbon, manganese, phosphorus and sulphur shall be made by the manufacturer from a test ingot taken during the pouring of each melt, a copy of which shall be given to the purchaser or his representative. This analysis shall conform to the requirements specified in Section 3. Drillings for analysis shall be taken not less than $\frac{1}{8}$ in. beneath the surface of the test ingot. **Ladle Analyses.**

Check Analyses.

5. Analyses may be made by the purchaser from finished splice bars representing each melt, in which case an excess of 25 per cent above the requirement as to phosphorus specified in Section 3 shall be allowed.

III. PHYSICAL PROPERTIES AND TESTS.

Tension Tests.

6. The splice bars shall conform to the following requirements as to tensile properties:

Tensile strength, lb. per sq. in. (See Section 7.)	68 000 – 83 000
Elongation in 2 in., min., per cent	$\frac{1\,600\,000}{\text{Tens. str.}}$

Permissible Variations in Tensile Strength.

7. The tensile strength may be over 83,000 to and including 85,000 lb. per sq. in., provided that the elongation in 2 in. is not under 20 per cent.

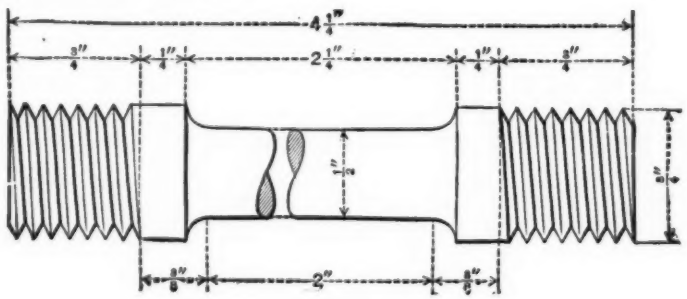


FIG. 1.

Bend Tests.

8. The bend test specimen specified in Section 9 shall bend cold through 180 deg. around a pin the diameter of which is equal to twice the thickness of the specimen, without cracking on the outside of the bent portion.

Test Specimens.

9. Tension and bend test specimens shall be taken from the finished bars. Tension test specimens shall be of the form and dimensions shown in Fig. 1. Bend test specimens may be $\frac{1}{2}$ in. square in section, or rectangular in section with two parallel faces as rolled.

Optional Bend Tests.

10. If preferred by the manufacturer and approved by the purchaser, the following bend test may be substituted for that described in Section 8: A piece of the finished bar shall bend

cold through 90 deg. around a pin the diameter of which is equal to twice the greatest thickness of the section, without cracking on the outside of the bent portion.

11. (*a*) One tension and one bend test shall be made from each melt. **Number of Tests.**

(*b*) If any test specimen shows defective machining or develops flaws, or if a tension test specimen breaks outside the gage length, it may be discarded and another specimen substituted.

IV. WORKMANSHIP AND FINISH.

12. The splice bars shall be smoothly rolled, true to templet, and shall accurately fit the rails for which they are intended. The bars shall be sheared to length, and the punching and notching shall conform to the dimensions specified by the purchaser. A variation of $\frac{1}{32}$ in. from the specified size and location of holes, and of $\frac{1}{8}$ in. from the specified length of splice bar, will be permitted. Any variation from a straight line in a vertical plane shall be such as will make the bars high in the center. The maximum camber in either plane shall not exceed $\frac{1}{16}$ in. in 24 in. **Workmanship.**

13. The finished splice bars shall be free from injurious defects and shall have a workmanlike finish. **Finish.**

V. MARKING.

14. The name or brand of the manufacturer and the year of manufacture shall be rolled in raised letters and figures on the side of the rolled bars, and a portion of this marking shall appear on each finished splice bar. **Marking.**

VI. INSPECTION AND REJECTION.

15. The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the splice bars ordered. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the splice bars are being furnished in accordance with these specifications. All tests (except check analyses) and inspection shall be made at the place of **Inspection.**

manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

Rejection. 16. (*a*) Unless otherwise specified, any rejection based on tests made in accordance with Section 5 shall be reported within five working days from the receipt of samples.

(*b*) Splice bars which show injurious defects subsequent to their acceptance at the manufacturer's works will be rejected, and the manufacturer shall be notified.

Rehearing. 17. Samples tested in accordance with Section 5, which represent rejected splice bars, shall be preserved for two weeks from the date of the test report. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time.

AMERICAN SOCIETY FOR TESTING MATERIALS

PHILADELPHIA, PA., U. S. A.

AFFILIATED WITH THE

INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

STANDARD SPECIFICATIONS

FOR

HIGH-CARBON STEEL SPLICE BARS.

ADOPTED AUGUST 25, 1913.

I. MANUFACTURE.

Process. 1. The steel shall be made by the open-hearth process.

Finishing. 2. The splice bars shall be punched, slotted and, in the case of special designs, shaped at a temperature not less than 750° C.

II. CHEMICAL PROPERTIES AND TESTS.

Chemical Composition. 3. The steel shall conform to the following requirements as to chemical composition:

Carbon	not under 0.45 per cent
Phosphorus	not over 0.04 "

Ladle Analyses. 4. An analysis to determine the percentages of carbon, manganese, phosphorus and sulphur shall be made by the manufacturer from a test ingot taken during the pouring of each melt, a copy of which shall be given to the purchaser or his representative. This analysis shall conform to the requirements specified in Section 3. Drillings for analysis shall be taken not less than $\frac{1}{8}$ in. beneath the surface of the test ingot.

Check Analyses.

5. Analyses may be made by the purchaser from finished splice bars representing each melt, in which case an excess of 25 per cent above the requirement as to phosphorus specified in Section 3 shall be allowed.

III. PHYSICAL PROPERTIES AND TESTS.

Tension Tests.

6. The splice bars shall conform to the following minimum requirements as to tensile properties:

Tensile strength, lb. per sq. in	85 000
Elongation in 2 in., per cent	14

Bend Tests.

7. The bend test specimen specified in Section 8 shall bend cold through 90 deg. around a pin the diameter of which is equal to three times the thickness of the specimen, without cracking on the outside of the bent portion.

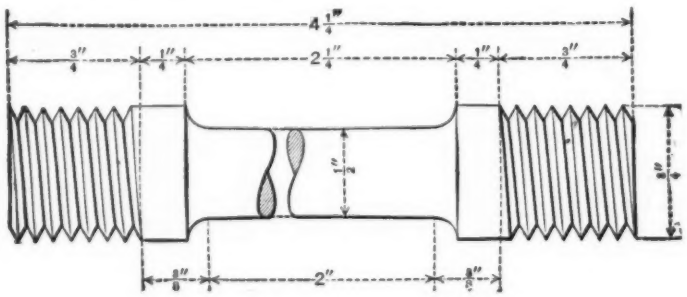


FIG. 1.

Test Specimens.

8. Tension and bend test specimens shall be taken from the finished bars. Tension test specimens shall be of the form and dimensions shown in Fig. 1. Bend test specimens may be ½ in. square in section, or rectangular in section with two parallel faces as rolled.

Optional Bend Tests.

9. If preferred by the manufacturer and approved by the purchaser, the following bend test may be substituted for that described in Section 7: A piece of the finished bar shall bend cold through 45 deg. around a pin the diameter of which is equal to three times the greatest thickness of the section, without cracking on the outside of the bent portion.

Number of Tests.

10. (*a*) One tension and one bend test shall be made from each melt.

(*b*) If any test specimen shows defective machining or develops flaws, or if a tension test specimen breaks outside the gage length, it may be discarded and another specimen substituted.

IV. WORKMANSHIP AND FINISH.

Workmanship.

11. The splice bars shall be smoothly rolled, true to templet, and shall accurately fit the rails for which they are intended. The bars shall be sheared to length, and the punching and notching shall conform to the dimensions specified by the purchaser. A variation of $\frac{1}{32}$ in. from the specified size and location of holes, and of $\frac{1}{8}$ in. from the specified length of splice bar, will be permitted. Any variation from a straight line in a vertical plane shall be such as will make the bars high in the center. The maximum camber in either plane shall not exceed $\frac{1}{16}$ in. in 24 in.

Finish.

12. The finished splice bars shall be free from injurious defects and shall have a workmanlike finish.

V. MARKING.

Marking.

13. The name or brand of the manufacturer and the year of manufacture shall be rolled in raised letters and figures on the side of the rolled bars, and a portion of this marking shall appear on each finished splice bar.

VI. INSPECTION AND REJECTION.

Inspection.

14. The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the splice bars ordered. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the splice bars are being furnished in accordance with these specifications. All tests (except check analyses) and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

Rejection.

15. (*a*) Unless otherwise specified, any rejection based on

tests made in accordance with Section 5 shall be reported within five working days from the receipt of samples.

(*b*) Splice bars which show injurious defects subsequent to their acceptance at the manufacturer's works will be rejected, and the manufacturer shall be notified.

Rehearing.

16. Samples tested in accordance with Section 5, which represent rejected splice bars, shall be preserved for two weeks from the date of the test report. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time.

AMERICAN SOCIETY FOR TESTING MATERIALS

PHILADELPHIA, PA., U. S. A.

AFFILIATED WITH THE

INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

STANDARD SPECIFICATIONS

FOR

EXTRA-HIGH-CARBON STEEL SPLICE BARS.

ADOPTED AUGUST 25, 1913.

I. MANUFACTURE.

1. The steel shall be made by the open-hearth process. **Process.**

2. The splice bars shall be punched, slotted, sheared and, in the case of special designs, shaped at a temperature not less than 750° C.; except that bars may be cold-sawed to length. **Finishing.**

II. CHEMICAL PROPERTIES AND TESTS.

3. The steel shall conform to the following requirement as to chemical composition: **Chemical Composition.**

Phosphorus.....not over 0.04 per cent

4. An analysis to determine the percentages of carbon, manganese, phosphorus and sulphur shall be made by the manufacturer from a test ingot taken during the pouring of each melt, a copy of which shall be given to the purchaser or his representative. This analysis shall conform to the requirement specified in Section 3. Drillings for analysis shall be taken not less than $\frac{1}{8}$ in. beneath the surface of the test ingot. **Ladle Analyses.**

Check Analyses.

5. Analyses may be made by the purchaser from finished splice bars representing each melt, in which case an excess of 25 per cent above the requirement specified in Section 3 shall be allowed.

III. PHYSICAL PROPERTIES AND TESTS.

Tension Tests.

6. The splice bars shall conform to the following minimum requirements as to tensile properties:

Tensile strength, lb. per sq. in.	100 000
Elongation in 2 in., per cent	10

Bend Tests.

7. The bend test specimen specified in Section 8 shall bend cold through 60 deg. around a pin the diameter of which is equal to three times the thickness of the specimen, without cracking on the outside of the bent portion.

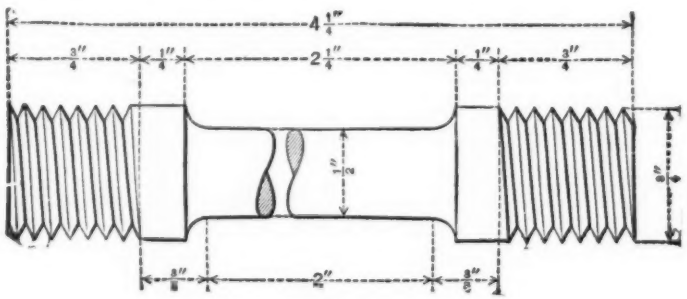


FIG. 1.

Test Specimens.

8. Tension and bend test specimens shall be taken from the finished bars. Tension test specimens shall be of the form and dimensions shown in Fig. 1. Bend test specimens may be ½ in. square in section, or rectangular in section with two parallel faces as rolled.

Optional Bend Tests.

9. If preferred by the manufacturer and approved by the purchaser, the following bend test may be substituted for that described in Section 7: A piece of the finished bar shall bend cold through 30 deg. around a pin the diameter of which is equal to three times the greatest thickness of the section, without cracking on the outside of the bent portion.

Number of Tests.

10. (*a*) One tension and one bend test shall be made from each melt.

(*b*) If any test specimen shows defective machining or develops flaws, or if a tension test specimen breaks outside the gage length, it may be discarded and another specimen substituted.

IV. WORKMANSHIP AND FINISH.

Workmanship.

11. The splice bars shall be smoothly rolled, true to templet, and shall accurately fit the rails for which they are intended. The bars shall be sheared to length, and the punching and notching shall conform to the dimensions specified by the purchaser. A variation of $\frac{1}{32}$ in. from the specified size and location of holes, and of $\frac{1}{8}$ in. from the specified length of splice bar, will be permitted. Any variation from a straight line in a vertical plane shall be such as will make the bars high in the center. The maximum camber in either plane shall not exceed $\frac{1}{16}$ in. in 24 in.

Finish.

12. The finished splice bars shall be free from injurious defects and shall have a workmanlike finish.

V. MARKING.

Marking.

13. The name or brand of the manufacturer and the year of manufacture shall be rolled in raised letter and figures on the side of the rolled bars, and a portion of this marking shall appear on each finished splice bar.

VI. INSPECTION AND REJECTION.

Inspection.

14. The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the splice bars ordered. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the splice bars are being furnished in accordance with these specifications. All tests (except check analyses) and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

Rejection.

15. (*a*) Unless otherwise specified, any rejection based on tests made in accordance with Section 5 shall be reported within five working days from the receipt of samples.

(*b*) Splice bars which show injurious defects subsequent to their acceptance at the manufacturer's works will be rejected, and the manufacturer shall be notified.

Rehearing.

16. Samples tested in accordance with Section 5, which represent rejected splice bars, shall be preserved for two weeks from the date of the test report. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time.

AMERICAN SOCIETY FOR TESTING MATERIALS

PHILADELPHIA, PA., U. S. A.

AFFILIATED WITH THE

INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

STANDARD SPECIFICATIONS FOR STRUCTURAL STEEL FOR SHIPS.[1]

ADOPTED AUGUST 25, 1913.

I. MANUFACTURE.

1. The steel shall be made by the open-hearth process. **Process.**

II. CHEMICAL PROPERTIES AND TESTS.

2. The steel shall conform to the following requirements as to chemical composition: **Chemical Composition.**

Phosphorous	Acid	not over 0.06 per cent
	Basic	" " 0.04 "
Sulphur		" " 0.05 "

3. An analysis to determine the percentages of carbon, manganese, phosphorus and sulphur shall be made by the manufacturer from a test ingot taken during the pouring of each melt, a copy of which shall be given to the purchaser or his representative. This analysis shall conform to the requirements specified in Section 2. **Ladle Analyses.**

4. Analyses may be made by the purchaser from finished material representing each melt, in which case an excess of 25 per cent above the requirements specified in Section 2 shall be allowed. **Check Analyses.**

[1] NOTE.—The requirements for castings for ships have been especially provided for in the Standard Specifications for Steel Castings, adopted August 25, 1913, by the American Society for Testing Materials (see Year-Book for 1913, pp. 127–132).

III. PHYSICAL PROPERTIES AND TESTS.

Tension Tests.

5. (*a*) The material shall conform to the following requirements as to tensile properties:

Tensile strength, lb. per sq. in.	58 000–68 000
Yield point, min., " "	0.5 tens. str.
Elongation in 8 in., min., per cent. (See Section 6.)	$\frac{1\,500\,000}{\text{Tens. str.}}$

(*b*) The yield point shall be determined by the drop of the beam of the testing machine.

Modification in Elongation.

6. (*a*) For material over $\frac{3}{4}$ in. in thickness, a deduction of 1 from the percentage of elongation specified in Section 5 (*a*) shall be made for each increase of $\frac{1}{8}$ in. in thickness above $\frac{3}{4}$ in., to a minimum of 18 per cent.

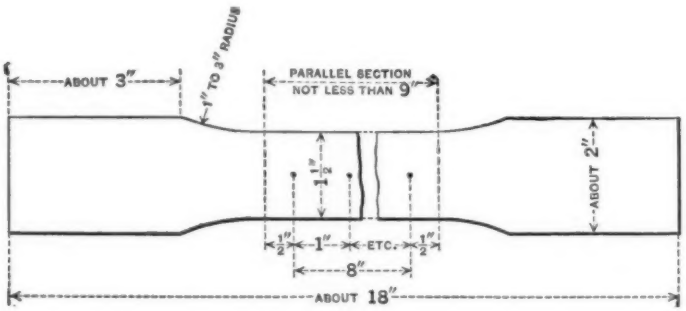


FIG. 1.

(*b*) For material $\frac{1}{4}$ in. or under in thickness, the elongation shall be measured on a gage length of 24 times the thickness of the specimen.

Bend Tests.

7. The test specimen shall bend cold through 180 deg. without cracking on the outside of the bent portion, as follows: For material $\frac{3}{4}$ in. or under in thickness, around a pin the diameter of which is equal to the thickness of the specimen; for material over $\frac{3}{4}$ in. to and including $1\frac{1}{4}$ in. in thickness, around a pin the diameter of which is equal to $1\frac{1}{2}$ times the thickness of the specimen; and for material over $1\frac{1}{4}$ in. in thickness, around a pin the diameter of which is equal to twice the thickness of the specimen.

Test Specimens.

8. (*a*) Tension and bend test specimens shall be taken from

the finished rolled material, and shall not be annealed or otherwise treated, except as specified in Paragraph (*b*).

(*b*) Tension and bend test specimens for material which is to be annealed or otherwise treated before use, shall be cut from properly annealed or similarly treated short lengths of the full section of the piece.

(*c*) Tension and bend test specimens, except as specified in Paragraph (*d*), shall be of the full thickness of material as rolled; and may be machined to the form and dimensions shown in Fig. 1, or with both edges parallel.

(*d*) Tension and bend test specimens for plates and bars over $1\frac{1}{2}$ in. in thickness or diameter may be machined to a thickness or diameter of at least $\frac{3}{4}$ in. for a length of at least 9 in.

Number of Tests.

9. (*a*) One tension and one bend test shall be made from each melt; except that if material from one melt differs $\frac{3}{8}$ in. or more in thickness, one tension and one bend test shall be made from both the thickest and the thinnest material rolled.

(*b*) If any test specimen shows defective machining or develops flaws, or if a tension test specimen breaks outside the middle third of the gage length, it may be discarded and another specimen substituted.

IV. PERMISSIBLE VARIATIONS IN WEIGHT AND GAGE.

Permissible Variations.

10. The cross-section or weight of each piece of steel shall not vary more than 2.5 per cent from that specified; except in the case of sheared plates, which shall be covered by the following permissible variations to apply to single plates:

(*a*) *When Ordered to Weight.*—For plates $12\frac{1}{2}$ lb. per sq. ft. or over:

Under 100 in. in width, 2.5 per cent above or below the specified weight;

100 in. in width or over, 5 per cent above or below the specified weight.

For plates under $12\frac{1}{2}$ lb. per sq. ft.:

Under 75 in. in width, 2.5 per cent above or below the specified weight;

75 to 100 in., exclusive, in width, 5 per cent above or 3 per cent below the specified weight;

100 in. in width or over, 10 per cent above or 3 per cent below the specified weight.

(*b*) *When Ordered to Gage.*—The thickness of each plate shall not vary more than 0.01 in. under that ordered.

An excess over the nominal weight corresponding to the dimensions on the order shall be allowed for each plate, if not more than that shown in the following table, one cubic inch of rolled steel being assumed to weigh 0.2833 lb.:

Thickness Ordered, in.	Nominal Weight, lb. per sq. ft.	Allowable Excess (expressed as percentage of Nominal Weight). For Width of Plate as follows:						
		Under 50 in.	50 to 70 in., excl.	70 in. or over.	Under 75 in.	75 to 100 in., excl.	100 to 115 in., excl.	115 in. or over.
$\frac{1}{8}$ to $\frac{5}{32}$	5.10 to 6.37	10	15	20	..	..	..	..
$\frac{5}{32}$ " $\frac{3}{16}$	6.37 " 7.65	8.5	12.5	17	..	..	..	..
$\frac{3}{16}$ " $\frac{1}{4}$	7.65 " 10.20	7	10	15	..	..	..	..
$\frac{1}{4}$	10.20	..	..	..	10	14	18	..
$\frac{5}{16}$	12.75	..	..	..	8	12	16	..
$\frac{3}{8}$	15.30	..	..	..	7	10	13	17
$\frac{7}{16}$	17.85	..	..	..	6	8	10	13
$\frac{1}{2}$	20.40	..	..	..	5	7	9	12
$\frac{9}{16}$	22.95	..	..	..	4.5	6.5	8.5	11
$\frac{5}{8}$	25.50	..	..	..	4	6	8	10
Over $\frac{5}{8}$	..	..	..	..	3.5	5	6.5	9

V. FINISH.

Finish. 11. The finished material shall be free from injurious defects and shall have a workmanlike finish.

VI. MARKING.

Marking. 12. The name or brand of the manufacturer and the melt number shall be legibly rolled or stamped on all finished material. The melt number shall be legibly stamped on each test specimen.

VII. INSPECTION AND REJECTION.

Inspection. 13. The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works

which concern the manufacture of the material ordered. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the material is being furnished in accordance with these specifications. All tests (except check analyses) and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

Rejection.

14. (*a*) Unless otherwise specified, any rejection based on tests made in accordance with Section 4 shall be reported within five working days from the receipt of samples.

(*b*) Material which shows injurious defects subsequent to its acceptance at the manufacturer's works will be rejected, and the manufacturer shall be notified.

Rehearing.

15. Samples tested in accordance with Section 4, which represent rejected material, shall be preserved for two weeks from the date of the test report. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time.

AMERICAN SOCIETY FOR TESTING MATERIALS

PHILADELPHIA, PA., U. S. A.

AFFILIATED WITH THE

INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

STANDARD SPECIFICATIONS

FOR

RIVET STEEL FOR SHIPS.

ADOPTED AUGUST 25, 1913.

A. Requirements for Rolled Bars.

I. MANUFACTURE.

Process. 1. The steel shall be made by the open-hearth process.

II. CHEMICAL PROPERTIES AND TESTS.

Chemical Composition. 2. The steel shall conform to the following requirements as to chemical composition:

Phosphorous	Acid	not over	0.06	per cent
	Basic	" "	0.04	"
Sulphur		" "	0.045	"

Ladle Analyses. 3. An analysis to determine the percentages of carbon, manganese, phosphorus and sulphur shall be made by the manufacturer from a test ingot taken during the pouring of each melt, a copy of which shall be given to the purchaser or his representative. This analysis shall conform to the requirements specified in Section 2.

Check Analyses. 4. Analyses may be made by the purchaser from finished bars representing each melt, in which case an excess of 25 per

cent above the requirements specified in Section 2 shall be allowed.

III. PHYSICAL PROPERTIES AND TESTS.

Tension Tests.

5. (*a*) The bars shall conform to the following requirements as to tensile properties:

Tensile strength, lb. per sq. in.	55 000 – 65 000
Yield point, min., " "	0.5 tens. str.
Elongation in 8 in., min., per cent	1 500 000
(See Section 6.)	Tens. str.

(*b*) The yield point shall be determined by the drop of the beam of the testing machine.

Modifications in Elongation.

6. For bars over $\frac{3}{4}$ in. in diameter, a deduction of 1 from the percentage of elongation specified in Section 5 (*a*) shall be made for each increase of $\frac{1}{8}$ in. in diameter above $\frac{3}{4}$ in.

Bend Tests.

7. The test specimen shall bend cold through 180 deg. flat on itself without cracking on the outside of the bent portion.

Test Specimens.

8. Tension and bend test specimens shall be of the full-size section of bars as rolled.

Number of Tests.

9. (*a*) Two tension and two bend tests shall be made from each melt, each of which shall conform to the requirements specified; except that if bars from one melt differ $\frac{3}{8}$ in. or more in diameter, one tension and one bend test shall be made from both the greatest and the least diameters rolled.

(*b*) If any test specimen develops flaws, or if a tension test specimen breaks outside the middle third of the gage length, it may be discarded and another specimen substituted.

IV. PERMISSIBLE VARIATIONS IN GAGE.

Permissible Variations.

10. The gage of bars 1 in. or under in diameter shall not vary more than 0.01 in. from that specified; the gage of bars over 1 in. to and including 2 in. in diameter shall not vary more than $\frac{1}{64}$ in under nor more than $\frac{1}{32}$ in. over that specified

V. FINISH.

Finish.

11. The finished bars shall be free from injurious defects and shall have a workmanlike finish.

VI. MARKING.

Marking.

12. Rivet bars shall, when loaded for shipment, be properly separated and marked with the name or brand of the manufacturer and the melt number for identification. The melt number shall be legibly marked on each test specimen.

VII. INSPECTION AND REJECTION.

Inspection.

13. The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the bars ordered. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the bars are being furnished in accordance with these specifications. All tests (except check analyses) and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

Rejection.

14. (*a*) Unless otherwise specified, any rejection based on tests made in accordance with Section 4 shall be reported within five working days from the receipt of samples.

(*b*) Bars which show injurious defects subsequent to their acceptance at the manufacturer's works will be rejected, and the manufacturer shall be notified.

Rehearing.

15. Samples tested in accordance with Section 4, which represent rejected bars, shall be preserved for two weeks from the date of the test report. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time.

B. Requirements for Rivets.

I. PHYSICAL PROPERTIES AND TESTS.

Test Certificate of Rolled Bars.

16. A copy of the results of tension tests of the rolled bars from which the rivets were made shall be furnished for each lot of rivets.

17. If the test certificate required in Section 16 cannot be furnished, the rivets shall conform to the requirements as to tensile properties specified in Sections 5 and 6, except that the elongation shall be measured on a gage length as great as the length of the rivets tested will permit. **Tension Tests.**

18. The rivet shank shall bend cold through 180 deg. flat on itself, as shown in Fig. 1, without cracking on the outside of the bent portion. **Bend Tests.**

19. The rivet head shall flatten, while hot, to a diameter $2\frac{1}{2}$ times the diameter of the shank, as shown in Fig. 2, without cracking at the edges. **Flattening Tests.**

20. (*a*) When required in accordance with Section 17, one tension test shall be made from each size in each lot of rivets offered for inspection. **Number of Tests.**

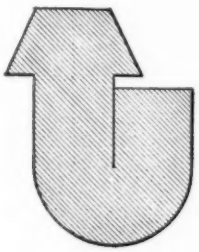


FIG. 1.

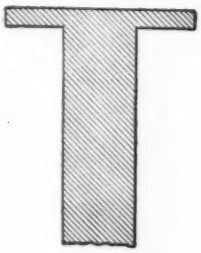


FIG. 2.

(*b*) Three bend and three flattening tests shall be made from each size in each lot of rivets offered for inspection, each of which shall conform to the requirements specified.

II. WORKMANSHIP AND FINISH.

21. The rivets shall be true to form, concentric, and shall be made in a workmanlike manner. **Workmanship.**

22. The finished rivets shall be free from injurious defects. **Finish.**

III. INSPECTION AND REJECTION.

23. The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which **Inspection.**

concern the manufacture of the rivets ordered. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the rivets are being furnished in accordance with these specifications. All tests and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

Rejection. 24. Rivets which show injurious defects subsequent to their acceptance at the manufacturer's works will be rejected, and the manufacturer shall be notified.

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STANDARD SPECIFICATIONS

FOR

RAIL-STEEL CONCRETE REINFORCEMENT BARS.

ADOPTED AUGUST 25, 1913.

Classes. 1. These specifications cover three classes of rail-steel concrete reinforcement bars, namely: plain, deformed. and hot-twisted.

I. MANUFACTURE.

Process. 2. The bars shall be rolled from standard section Tee rails.

Hot-twisted Bars. 3. Hot-twisted bars shall have one complete twist in a length not over 12 times the thickness of the bar.

II. PHYSICAL PROPERTIES AND TESTS.

Tension Tests 4. (*a*) The bars shall conform to the following minimum requirements as to tensile properties:

Properties Considered.	Plain Bars.	Deformed and Hot-twisted bars.
Tensile strength, lb. per sq. in.	80 000	80 000
Yield point, lb. per sq. in.	50 000	50 000
Elongation in 8 in., per cent[1]	$\frac{1\,200\,000}{\text{Tens. str.}}$	$\frac{1\,000\,000}{\text{Tens. str.}}$

[1] See Section 5.

(*b*) The yield point shall be determined by the drop of the beam of the testing machine.

Modifications in Elongation.

5. (*a*) For bars over $\frac{3}{4}$ in. in thickness or diameter, a deduction of 1 from the percentages of elongation specified in Section 4 (*a*) shall be made for each increase of $\frac{1}{8}$ in. in thickness or diameter above $\frac{3}{4}$ in.

(*b*) For bars under $\frac{7}{16}$ in. in thickness or diameter, a deduction of 1 from the percentages of elongation specified in Section 4 (*a*) shall be made for each decrease of $\frac{1}{16}$ in. in thickness or diameter below $\frac{7}{16}$ in.

Bend Tests.

6. The test specimen shall bend cold around a pin without cracking on the outside of the bent portion, as follows:

Thickness or Diameter of Bar.	Plain Bars.	Deformed and Hot-twisted Bars.
Under $\frac{3}{4}$ in.	180 deg d = 3 t	180 deg. d = 4 t
$\frac{3}{4}$ in. or over	90 deg d = 3 t	90 deg. d = 4 t

EXPLANATORY NOTE: d = the diameter of pin about which the specimen is bent;
t = the thickness or diameter of the specimen.

Test Specimens.

7. (*a*) Tension and bend test specimens for plain and deformed bars shall be taken from the finished bars, and shall be of the full thickness or diameter of bars as rolled; except that the specimens for deformed bars may be machined for a length of at least 9 in., if deemed necessary by the manufacturer to obtain uniform cross-section.

(*b*) Tension and bend test specimens for hot-twisted bars shall be taken from the finished bars, without further treatment.

Number of Tests.

8. (*a*) One tension and one bend test shall be made from each lot of ten tons or less of each size of bar rolled from rails varying not more than 10 lb. per yd. in nominal weight.

(*b*) If any test specimen shows defective machining or develops flaws, or if a tension test specimen breaks outside the middle third of the gage length, it may be discarded and another specimen substituted.

III. PERMISSIBLE VARIATIONS IN WEIGHT.

Permissible Variations.

9. The weight of any lot of bars shall not vary more than 5 per cent from the theoretical weight of that lot.

IV. FINISH.

10. The finished bars shall be free from injurious defects and shall have a workmanlike finish. **Finish.**

V. INSPECTION AND REJECTION.

11. The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the bars ordered. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the bars are being furnished in accordance with these specifications. All tests and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works. **Inspection.**

12. Bars which show injurious defects subsequent to their acceptance at the manufacturer's works will be rejected, and the manufacturer shall be notified. **Rejection.**

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STANDARD SPECIFICATIONS

FOR

COLD-ROLLED STEEL AXLES.

ADOPTED AUGUST 25, 1913.

I. MANUFACTURE.

Process.

1. (*a*) The steel may be made by the open-hearth or any other process approved by the purchaser.

(*b*) The axles shall be cold-rolled to finished size from hot-rolled bars.

Discard.

2. A sufficient discard shall be made from each ingot to secure freedom from injurious piping and undue segregation.

II. CHEMICAL PROPERTIES AND TESTS.

Chemical Composition.

3. The steel shall conform to the following requirements as to chemical composition:

Carbon	not over 0.40 per cent
Manganese	0.40 – 0.80 "
Phosphorus	not over 0.05 "
Sulphur	" " 0.05 "

Ladle Analyses.

4. An analysis shall be made by the manufacturer from a test ingot taken during the pouring of each melt, a copy of which shall be given to the purchaser or his representative. This analysis shall conform to the requirements specified in Section 3.

5. Analyses may be made by the purchaser from an axle representing each melt, which shall conform to the requirements specified in Section 3. Drillings for analysis shall be taken from the axle or from the full-size prolongation of the same, at any point midway between the center and surface. **Check Analyses.**

III. PHYSICAL PROPERTIES AND TESTS.

6. (*a*) The axles shall conform to the following minimum requirements as to tensile properties: **Tension Tests.**

Tensile strength, lb. per sq. in.	70 000
Elastic limit, lb. per sq. in.	60 000
Elongation in 2 in., per cent	18
Reduction of area, "	35

(*b*) The elastic limit shall be determined by means of an extensometer.

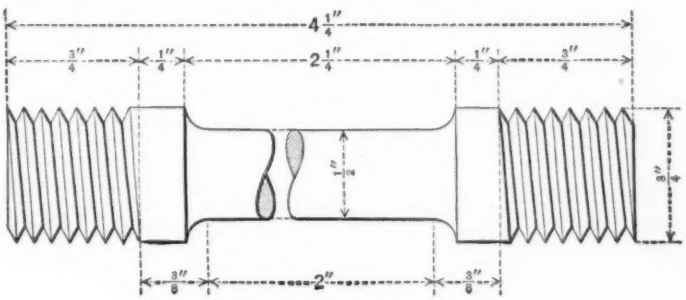


FIG. 1.

7. The test specimen shall bend cold through 180 deg. around a 1-in. pin or mandrel, without cracking on the outside of the bent portion. **Bend Tests.**

8. (*a*) Tension and bend test specimens shall be taken from the full-size prolongation of the axle. The axis of the specimen shall be located at any point midway between the center and surface and shall be parallel to the axis of the axle. **Test Specimens.**

(*b*) Tension test specimens shall be of the form and dimensions shown in Fig. 1. Bend test specimens shall be $\frac{1}{2}$ in. square in section with corners rounded to a radius not over $\frac{1}{16}$ in., and need not exceed 6 in. in length.

9. (*a*) One tension and one bend test shall be made from each lot of 50 axles or less from each melt. **Number of Tests.**

(*b*) If any test specimen shows defective machining or develops flaws, or if a tension test specimen breaks outside the gage length, it may be discarded and another specimen substituted.

IV. WORKMANSHIP AND FINISH.

Workmanship.

10. The axles shall conform to the sizes and shapes specified by the purchaser, and shall not vary more than 0.002 in. from the diameter specified. When centered, 60-deg. centers shall be used with clearance drilled for the points.

Finish.

11. The axles, either finished or plain, shall be straight and free from injurious defects, and shall have a workmanlike finish.

V. MARKING.

Marking.

12. Identification marks shall be legibly stamped on each axle, and on each test specimen. Unless otherwise specified, such marks shall be stamped at about the middle of the length of the axle.

VI. INSPECTION AND REJECTION.

Inspection.

13. (*a*) The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the axles ordered. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the axles are being furnished in accordance with these specifications. Tests and inspection at the place of manufacture shall be made prior to shipment.

(*b*) The purchaser may make the tests to govern the acceptance or rejection of axles in his own laboratory or elsewhere. Such tests, however, shall be made at the expense of the purchaser.

(*c*) All tests and inspection shall be so conducted as not to interfere unnecessarily with the operation of the works.

Rejection.

14. (*a*) Unless otherwise specified, any rejection based on tests made in accordance with Section 13 (*b*) shall be reported within five working days from the receipt of samples.

(*b*) Axles which show injurious defects while being finished by the purchaser will be rejected, and the manufacturer shall be notified.

15. Samples tested in accordance with Section 13 (*b*), which represent rejected axles, shall be preserved for two weeks from the date of the test report. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time. Rehearing.

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STANDARD SPECIFICATIONS

FOR

WROUGHT SOLID CARBON-STEEL WHEELS FOR ELECTRIC RAILWAY SERVICE

(WITH NARROW TREADS AND SMALL FLANGES).

ADOPTED AUGUST 25, 1913.

I. MANUFACTURE.

Process. 1. The steel shall be made by the open-hearth process.

Discard. 2. A sufficient discard shall be made from each ingot to insure freedom from injurious piping and undue segregation.

II. CHEMICAL PROPERTIES AND TESTS.

Chemical Composition. 3. The steel shall conform to the following requirements as to chemical composition:

	Acid.	Basic.	
Carbon	0.60 – 0.80	0.65 – 0.85	per cent
Manganese	0.55 – 0.80	0.55 – 0.80	"
Phosphorus	not over 0.05	not over 0.05	"
Sulphur	" " 0.05	" " 0.05	"
Silicon	0.15 – 0.35	0.10 – 0.30	"

Ladle Analyses. 4. To determine whether the material conforms to the requirements specified in Section 3, an analysis shall be made

by the manufacturer from a test ingot taken during the pouring of each melt. A copy of this analysis, together with such identifying records as may be desired, shall be given to the purchaser or his representative.

Check Analyses.

5. A check analysis may be made by the purchaser from one wheel representing each melt, and this analysis shall conform to the requirements specified in Section 3. A sample may be taken from any one point in the plate; or two samples may be taken, in which case they shall be on radii at right angles to each other. Samples shall not be taken in such a way as to impair the usefulness of the wheel. Drillings for analysis shall be taken by boring entirely through the sample parallel to the axis of the wheel; they shall be clean and free from scale, oil and other foreign substances. All drillings from any one wheel shall be thoroughly mixed together.

III. TOLERANCES.

Tolerances.

6. The wheels shall be machined on both sides of the hub, and contour,[1] rough-bored, and shall conform to the dimensions shown on the drawing approved by the purchaser and subject to the tolerances herein provided; or if specified by the purchaser, wheels may be furnished as rolled, provided they conform to the tolerances herein provided. Where wheels are specified by the purchaser to be furnished as rolled, it is understood that where any machining is necessary rolled tolerances shall govern.

(*a*) *Height of Flange.*—The height of flange for machined wheels shall not vary more than $\frac{1}{32}$ in. from that specified; for rolled wheels, shall not vary more than $\frac{1}{16}$ in. from that specified.

(*b*) *Thickness of Flange.*—The thickness of flange for machined wheels shall not vary more than $\frac{1}{32}$ in. from that specified; for rolled wheels, shall not vary more than $\frac{1}{16}$ in. from that specified.

(*c*) *Radius of Throat.*—The radius of throat for machined wheels shall not vary more than $\frac{1}{32}$ in. from that specified; for rolled wheels, shall not vary more than $\frac{1}{16}$ in. from that specified.

[1] Contour includes the front face of rim, tread, flange and back face of rim.

(*d*) *Thickness of Rim.*—The thickness of rim shall not vary more than $\frac{1}{4}$ in. over nor more than $\frac{1}{8}$ in. under that specified. The thickness of rim shall be measured from a base line drawn from the intersection of the throat radius and the tread, parallel to the axis of the wheel.

(*e*) *Width of Rim.*—The width of rim for machined wheels shall not vary more than $\frac{1}{16}$ in. from that specified; for rolled wheels, shall not vary more than $\frac{1}{8}$ in. from that specified.

(*f*) *Thickness of Plate.*—The thickness of plate shall not vary more than $\frac{1}{4}$ in. over nor more than $\frac{1}{8}$ in. under that specified.

(*g*) *Limit Groove.*—When limit groove is specified, the location of the center line of the limit-of-wear groove shall not vary more than $\frac{1}{16}$ in. from that specified.

(*h*) *Diameter of Rough Bore.*—The diameter of rough bore shall not vary more than $\frac{1}{16}$ in. over nor more than $\frac{1}{8}$ in. under that specified. When not specified, the diameter of rough bore shall be $\frac{1}{4}$ in. less than that of the finished bore, subject to the above limitations.

(*i*) *Diameter of Hub.*—The diameter of hub shall not be less, but may be $\frac{5}{8}$ in. more than that specified. The thickness of wall of the finished bored hub shall not be less than 1 in. at any point for bores 6 in. in diameter or under, nor less than $1\frac{1}{4}$ in. for bores over 6 in. in diameter, unless otherwise specified. The thickness of wall of the hub shall not vary more than $\frac{3}{8}$ in. at any two points on the same wheel.

(*j*) *Length of Hub.*—The length of hub shall not vary more than $\frac{1}{8}$ in. from that specified.

(*k-1*) *Projection of Front Face of Hub.*—The projection of the front face of hub from the gage line shall not vary more than $\frac{1}{8}$ in. from that specified.

(*k-2*) *Projection of Back Face of Hub.*—The projection of the back face of hub from the gage line shall not

vary more than $\frac{1}{32}$ in. over nor more than $\frac{1}{16}$ in. under that specified.

(*l*) *Black Spots in Hub.*—Black spots in rough bore within 2 in. of either face of the hub shall not exceed $\frac{1}{16}$ in. in depth.

(*m*) *Eccentricity of Bore.*—The eccentricity between the tread at its center line and the rough bore shall not exceed $\frac{3}{64}$ in.

(*n*) *Block Marks on Tread.*—Block marks shall not exceed $\frac{1}{64}$ in. in height.

(*o*) *Rotundity.*—The wheels shall be gaged with a ring gage, and the opening between the gage and tread at any point shall not exceed $\frac{1}{32}$ in. for machined wheels, nor $\frac{1}{16}$ in. for rolled wheels.

(*p*) *Plane.*—The wheels shall be gaged with a ring gage placed concentric with and perpendicular to the axis of the wheel. All points on the back of the rim equidistant from the center shall be within a variation of $\frac{1}{32}$ in. for machined wheels and $\frac{1}{16}$ in. for rolled wheels from the plane of the gage when so placed.

(*q*) *Tape Sizes.*—The wheels shall not vary more than four tapes under nor more than six tapes over the size specified.

(*r*) *Mating.*—The wheels shall be mated as to tape sizes and shipped in pairs.

Gages and Tapes.

7. The manufacturer shall provide suitable gages and tapes which shall conform to the contour and dimensions shown on the drawing and approved by the purchaser.

IV. FINISH.

Finish.

8. (*a*) The wheels shall be free from injurious seams, cracks, laminations or other defects detrimental to their strength or service.

(*b*) The wheels offered for inspection shall not be painted or covered with any substance that will hide defects, nor rusted to such an extent as to hide defects.

V. MARKING.

Marking. 9. The name or brand and serial number of the manufacturer and the melt number shall be legibly stamped on each wheel; and also, if specified, the name and serial number of the purchaser. The marking shall be done in accordance with Master Car Builders' recommended practice, Fig. 1.

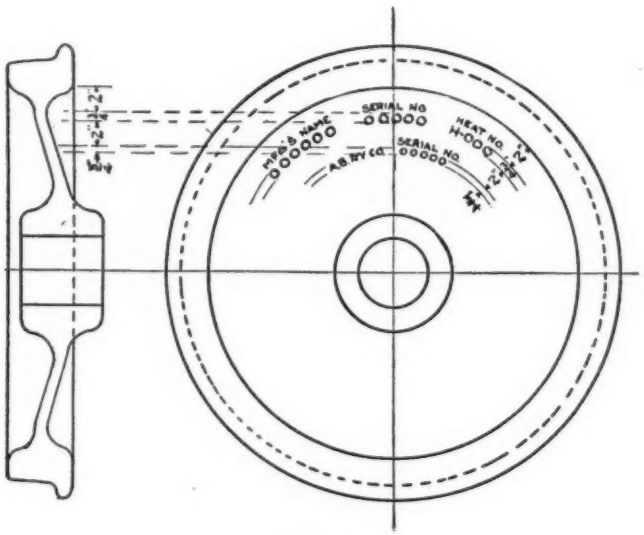


FIG. 1.

VI. INSPECTION AND REJECTION.

Inspection. 10. (*a*) The inspector representing the purchaser shall have free entry at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the wheels ordered. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the wheels are being furnished in accordance with these specifications. Tests and inspection at the place of manufacture shall be made prior to shipment.

(*b*) The purchaser may make the tests to govern the acceptance or rejection of wheels in his own laboratory or else-

where. Such tests, however, shall be made at the expense of the purchaser.

(*c*) All tests and inspection shall be so conducted as not to interfere unnecessarily with the operation of the works.

11. (*a*) Unless otherwise specified, any rejection based on tests made in accordance with Section 10 (*b*) shall be reported within ten working days from receipt of samples. **Rejection.**

(*b*) Wheels which show injurious defects while being finished by purchaser will be rejected, and the manufacturer shall be notified.

12. Samples tested in accordance with Section 10 (*b*), which represent rejected wheels, shall be preserved for one month from the date of the test report. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time. **Rehearing.**

13. The manufacturer shall replace free of charge any wheels that may fail by reason of defective material or workmanship. **Replacement.**

AMERICAN SOCIETY FOR TESTING MATERIALS

PHILADELPHIA, PA., U. S. A.

AFFILIATED WITH THE

INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

STANDARD SPECIFICATIONS

FOR

BLOOMS, BILLETS AND SLABS FOR CARBON-STEEL FORGINGS.

ADOPTED AUGUST 25, 1913.

Classes.

1. (*a*) These specifications cover five classes of billets, determined by their carbon ranges as specified in Section 6.

(*b*) The purposes for which these classes are frequently used are as follows:

Class A, for welding and case hardening;

Class B, for case hardening when subsequently heat-treated;

Class C, for special purposes;

Class D, for axles, shafts, connecting rods and similar forgings;

Class E, for Class D forgings when they are to be heat-treated.

Definition of Terms.

2. The term "billets" will be used in these specifications to designate blooms, billets and slabs.

Basis of Purchase.

3. (*a*) Billets shall be purchased as semi-finished rolled or forged material. In ordering, all dimensions shall be expressed in feet and inches.

(*b*) Unless otherwise specified, the billets shall be made from ingots of at least four times the sectional area of the billet.

I. MANUFACTURE.

4. The steel shall be made by the open-hearth process. **Process.**

5. A sufficient discard shall be made from each ingot to secure freedom from injurious piping and undue segregation. **Discard.**

II. CHEMICAL PROPERTIES AND TESTS.

6. The steel shall conform to the following requirements as to chemical composition:[1] **Chemical Composition.**

Elements Considered.	Class.				
	A	B	C	D	E
Carbon, per cent.[2]	0.08–0.18	0.15–0.25	0.25–0.38	0.38–0.52	0.45–0.60
Manganese, per cent	0.30–0.50	0.30–0.50	0.40–0.60	0.40–0.60	0.45–0.70
Phosphorus, max., per cent	0.045	0.045	0.045	0.045	0.045
Sulphur, max., per cent.	0.05	0.05	0.05	0.05	0.05

[2] See Section 8 (*b*).

7. An analysis shall be made by the manufacturer from a test ingot taken during the pouring of each melt, a copy of which shall be given to the purchaser or his representative. This analysis shall conform to the requirements specified in Section 6. **Ladle Analyses.**

8. (*a*) Analyses may be made by the purchaser from at least one billet representing each melt, which shall conform to the requirements specified in Section 6. Drillings for analysis shall be taken from the billet with a $\frac{5}{8}$-in. drill, parallel to the axis of the ingot as cast, at any point midway between the center and surface. **Check Analyses.**

(*b*) In addition to the complete analysis specified in Paragraph (*a*), a carbon determination may be made by the purchaser of drillings taken from the center of the billet with a $\frac{5}{8}$-in. drill, parallel to the axis of the ingot as cast, to determine by the variation in carbon the amount of segregation.

III. WORKMANSHIP AND FINISH.

9. The billets may be chipped to a depth not over $\frac{1}{2}$ in., unless otherwise specified. Chipping shall be done in such a manner as not to cause laps when the billets are properly forged. **Chipping.**

[1] The chemical requirements as to manganese and phosphorus have purposely been made somewhat lower than those in the standard specifications for finished products for the protection of the purchaser of billets, so that with reasonable variations from segregation in the billets the finished product will meet the specified chemical requirements.

Finish. 10. The billets shall be free from injurious defects and shall have a workmanlike finish.

IV. MARKING.

Marking. 11. The melt number shall be legibly stamped on each billet 6 in. or over in thickness; and the top end of all "top cut" billets of such sizes shall be hot-stamped with the letter "T" and such ends criss-crossed with green paint. The melt number shall be legibly stamped on billets of smaller section when specified.

V. INSPECTION AND REJECTION.

Inspection. 12. (*a*) The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the billets ordered. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the billets are being furnished in accordance with these specifications. Tests and inspection at the place of manufacture shall be made prior to shipment.

(*b*) The purchaser may make the tests to govern the acceptance or rejection of billets in his own laboratory or elsewhere. Such tests, however, shall be made at the expense of the purchaser.

(*c*) All tests and inspection shall be so conducted as not to interfere unnecessarily with the operation of the works.

Rejection. 13. (*a*) Unless otherwise specified, any rejections based on tests made in accordance with Section 12 (*b*) shall be reported within five working days from the receipt of samples.

(*b*) Billets which show injurious defects while being finished by the purchaser will be rejected, and the manufacturer shall be notified.

Rehearing. 14. Samples tested in accordance with Section 12 (*b*), which represent rejected billets, shall be preserved for two weeks from the date of the test report. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time.

DISCUSSION ON THE REPORT OF COMMITTEE A-1.

Discussion on Steel Reinforcement Bars.

Mr. A. L. Johnson (*by letter*).—Professor Hatt is to be complimented on the very full manner in which he has gone into the subject of rail-steel concrete reinforcement bars, it being one which does not lend itself readily to scientific analysis. A careful perusal of the report, however, has not convinced the writer of the advisability of the use of rerolled material for concrete reinforcement, his position being somewhat influenced by the experience had by the Corrugated Bar Co. throughout a period of five years—from 1900 to 1905—during which time large quantities of such material were purchased from different rerolling mills. Mr. Johnson.

The writer's attitude at that time, as engineer of the company, was very similar to the position now taken by Professor Hatt, namely, that the same amount of ductility is not required in reinforced concrete as in steel structures, and the nature of such construction makes the integrity of the structure independent of an occasional defective bar. In those days, the contractors, not fully realizing the scientific nature of the construction, and the necessity for care in the execution thereof, were not fitted to handle work designed with a small factor of safety. Greater allowance was made by the designers at that time for defective concrete, and an occasional defective reinforcing bar could not materially affect the integrity of the structure.

While it is still the custom to design structures with a liberal margin of safety, where they are to be erected by unknown parties, the bulk of the work of to-day is designed with a much smaller factor of safety than was customary a few years ago, the reason being that in all parts of the country there are now experienced contractors who realize that it is dangerous to "skin" cement on a reinforced concrete job. This leaves less latitude to-day than formerly for variation in quality of the reinforcement. To the writer it seems like a "throw back" to consider making a standard specification for a material which

Mr. Johnson. was so persistently and extensively tried by his company through a period of five years, and then abandoned.

Just the moment that we abandoned rerolled material for billet stock our troubles ceased, so far as the physical qualifications of the reinforcement were concerned. We had practically no rejections on billet stock. To-day we have some trouble, but the rejections are small, as compared with what they would be according to Professor Hatt's tests on rerolled material, which show 16 per cent for twisted and 5 per cent for other bars. Our rejections average about 0.5 per cent.

It is unquestionably true that the quality of billet stock to-day is below that of a few years ago, the main reason, in the writer's opinion, being the gradually increased roll speed, giving a much higher finishing temperature than was formerly the practice. There is no interior work done on the material to-day, and the required elastic limit has to be obtained by the addition of carbon.

Although our rejections at the present time are only averaging about 0.5 per cent, as above stated, yet it is astonishing how annoying that is. It nearly always develops on the job, and generally when the work is at high pressure. The material has to be obtained immediately, and often at great expense, and the contractor frequently demands that the company supplying the bars shall indemnify him for so many days delay, at so much per day, in accordance with the forfeiture clause in his contract with the owner.

To suggest that we multiply our present troubles of this kind by ten is not to be thought of. Of course, if the contractor could make the bar company pay, in each case, all his extra cost, whether in money, time or worry, he would probably figure on using rerolled material on the next job, because he could unquestionably always make his original purchase for less money.

These things will, of course, come to be understood eventually, and eventually the consumer will pay. But if, as shown by Professor Hatt's tests, rejection would be ten times as great with this material as with billet stock, then it seems evident to the writer that it is not a proper material to use for such purposes.

It may be true that if the bars have to be bent, and a given

bar stands the bending, the chances are that it will perform its functions in the structure satisfactorily, although even this is open to question. But this is not the proper way to view the matter. In sending 3000 billet-stock reinforcing bars to a job, there will be on the average, at the present time, 30 bars rejected. It is possible that these 30 bars may be picked up locally; if not, they will have to be sent from the nearest stock. In the rerolled material, there would be 150 bars to replace. In the case of the billet bars, two panels of a floor could probably not be concreted. In the rerolled material, it might be half of a floor. Mr. Johnson.

I notice that the bars in Professor Hatt's tests were bent on the twisting head of a torsion machine. As I understand the operation, it leaves the bar free at both ends to move longitudinally, which certain types of bar benders do not, resulting in an increased stress in the tension fiber, amounting to from 15,000 to 20,000 lb. per sq. in. over and above the natural fiber stress due to bending. One of the hardest problems that has confronted the Corrugated Bar Co. has been the defective bending methods employed in the field, and we are about to issue a monograph on this subject. If Professor Hatt had used on this rerolled material some of the standard types of bending machines, he would probably have found several times the quantity of defective material.

A reheating furnace with a length of 15 ft. is larger than the average. Assuming that the head of the rail weighs 15 lb. per ft., this gives a billet weight of 225 lb., and the recommendation made in the proposed specifications, of one test for every 10 tons, would mean about a hundred billets, which would represent a hundred different kinds of steel. One test for every 10 tons of new billet stock is a test for every ingot, which is all supposed to be of the same grade of steel. Of course, we know there is considerable variation of material in the same ingot, but a hundred different billets may represent a hundred different ingots, made at a dozen different mills, and not necessarily made even in this country.

One of these 225-lb. billets would make four reinforcing bars of average size and length, so that a 10-ton lot would represent about 400 pieces. When the contractor and the

Mr. Johnson. engineer came to realize that any given reinforcing bar on the work had only one chance in 400 of being represented by the test that had been made from the 10-ton lot, he would be very likely to conclude that the test was not worth while, and it would undoubtedly become the custom to call for no tests at all on this class of material. This would leave it open to the better informed manufacturer—who knows that some lots which he has purchased are poor—to run in large quantities of defective material, which may come together in the work, destroying the force of the argument relating to the distributing effect of the concrete. This is not a mere academic theory, but represents a part of our five years' experience.

It is often argued that while in the past rails were poorly made, and therefore one would be taking considerable chance in using reinforcement made of such material, yet in the course of time this argument was bound to become less and less effective as the higher grade rails began to reach the rerolling market. Specifications for rails have certainly become, year by year, more and more rigid, except as to one point, which the writer considers to be the key-note of the situation. The specifications have not dealt with the finishing temperature, which is higher to-day in all rolled products than ever before, and is, in the writer's opinion, much higher than should be permitted, where quality in the output is required.

I may cite in further support of my position that the improvement in rail quality is questionable, the paper on "Rail Failures and Their Causes," by Mr. M. H. Wickhorst, to be presented at this meeting of the Society,[1] in which he says:

> "As an example may be mentioned a lot of 2500 tons of 80-lb. A. S. C. E. Bessemer rails, rolled in September, 1909, and placed into track in October, 1909. Up to May, 1912, or, in a period of 2½ years, there were 510 failures, classified by the trackmen as follows: [He then gives the classification]. This would be 2040 failures per 10,000 tons; or, figured on the basis of 30-ft. lengths, there would be one failure in each 13.7 rails in 2½ years from the time the rails were put into service."

This does not, to my mind, indicate an improvement in quality of the modern output of this material.

In conclusion, I wish to say that while I consider the paper

[1] See pp. 582-593.—ED.

an excellent one, and the tests well worth while, I think the results, taken for their face value, are sufficient to condemn the consideration of the material as a reinforcement for concrete on any important work whatsoever, and strongly urge that the Society shall not, at present at any rate, adopt a standard specification for this class of reinforcement. **Mr. Johnson.**

MR. A. E. LINDAU (*by letter*).—The writer is particularly interested in the work done under Professor Hatt's direction to determine the physical properties of rerolled rail steel reinforcing bars. **Mr. Lindau.**

For a period of several years it was the writer's duty to examine the test reports of reinforcing bars shipped to all parts of the United States, and shipments were made from various mills including some from which rerolled steel was shipped exclusively. The principal points noted in the reports were the results of bending tests, elongation, and tension tests.

When rejection was reported by the inspection bureaus or breakage in bending by customers, special attention was given the reports in order to discover, if possible, the relation between the properties noted on the test reports and the nature of the failure. It was found in general, that the tests on rerolled material gave little indication of the results that might be expected by handling the bars in the field. The principal difficulty that developed was breakage in cold-bending. In fact, it became generally acknowledged that rerolled bars were brittle, which opinion is indeed quite general at the present time. Without any prejudice on the part of the writer, or anyone connected with our company (the Corrugated Bar Co.), we were forced to conclude from our experience in handling rerolled bars in large and small quantities, in warm and cold weather, in fact, in all conditions, that the percentage of failure in bending under field conditions was much larger than in the new billet-stock bars of the same ultimate strength and elastic limit. It is of importance to note in this connection, that we naturally minimized the extent of the failures, and that instead of forming a prejudiced opinion, the tendency was entirely the contrary.

The writer is keenly aware of the fact that he is offering some rather hap-hazard evidence in the discussion of the comprehensive and carefully executed test program, but if the

Mr. Lindau. "proof of the pudding is the eating," the experience of the company with which the writer is connected, in making every-day use of rerolled material for several years under all conditions that are likely to occur, cannot lightly be set aside in the consideration of this material as a standard for reinforcing purposes.

Mr. Hatt. MR. W. K. HATT (*by letter*).—Mr. Johnson's discussion of the writer's report raises questions that are apart from the content of the paper, the purpose of which is to submit the data upon which Committee A-1 based its action. An engineer who has to select a reinforcing bar for a given service must use his own judgment as to which kind of bar most nearly fulfils the service expected of it.

The writer chose a bending machine which would preserve constant conditions for all the bars, certainly a necessary condition; and a sliding bearing, and a sleeve over the pin, is of advantage.

DISCUSSION ON STEEL SPLICE BARS.

Mr. Litchfield. MR. NORMAN LITCHFIELD.—The representatives of the American Electric Railway Engineering Association have been working in conference with your committee in the preparation of specifications for splice bars, and while they have no great objections to the use of four different specifications, they feel that these specifications as your committee has written them are not applicable to girder-rail work, in that the tolerances permit of too great a variation to enable us to get as accurate a joint fit as is essential in girder-rail work. We believe that the committee has erred in the tolerances permitted in Section 12 of the proposed Standard Specifications for Medium-Carbon Steel Splice Bars, and in Section 11 of the proposed Standard Specifications for High-Carbon and for Extra-High-Carbon Steel Splice Bars, in that it is proposed to allow a vertical camber of $\frac{1}{16}$ in. in 24 in. in these splice bars. There are a great number of purchasers and users of girder-rail splice bars, while there are only a few manufacturers, and at least one of these manufacturers willingly consents to a vertical camber of $\frac{1}{32}$ in. Another states that in special cases he can comply with such a camber, but thinks the tolerance of $\frac{1}{16}$ in. vertical camber sufficient for a general specification. The specifications as

drawn up, therefore, apparently give greater weight to the opinion of one manufacturer than to the users. **Mr. Litchfield.**

The representatives of the Association further feel that it should be specified that the variation from a straight line in a horizontal plane, if any, shall be such as shall make it convex towards the rail (that is, in contact with the rail first at the joint between rails), for the reason that this is the most essential point in the joint where an accurate fit should be obtained, and where the joint first becomes defective. The initial wear always shows at this point first, and for the further reason that such a splice bar, fitting accurately at the joint between the rails, can be drawn in with less difficulty to fit the rail for the entire length of the splice bar, by the application of power in tightening up the end bolts.

I might add that the specifications which the committee of the American Electric Railway Engineering Association has been working on this winter, will probably be modified so as to bring some of the other points more nearly in line with the specifications before this meeting, and will be presented to the convention of the Association in October.

For the foregoing reasons, we believe that the specifications are not applicable in their present form to girder rails, and we therefore recommend the changes above outlined. If these do not meet with your approval, we wish to vote against their adoption.

MR. E. F. KENNEY (*Chairman, Sub-Committee on Splice Bars*).—In regard to the points raised by the gentleman who has just spoken: they were both considered at considerable length at a number of different committee meetings, and the consensus of opinion seemed to be that while there are a certain number of customers who require the very great nicety spoken of by Mr. Litchfield, the majority do not require anything of the sort, even in girder-rail work. The two manufacturers on the committee stated that a few customers required it, but the majority did not. **Mr. Kenney.**

As to the convexity of the splice bar to the rail in the horizontal plane, I sent out letters to a number of the engineers of maintenance of way on the different railroads, asking them whether they preferred convexity toward the rail or concavity, or whether they would prefer to aim at straightness; and in

Mr. Kenney. almost all the replies they stated that they preferred a straight bar, and that what variation was necessary to meet practical requirements they preferred to have in one direction or the other rather than to aim at a crooked bar.

DISCUSSION ON STEEL WHEELS.

Mr. Stevenson. MR. A. A. STEVENSON (*Chairman, Sub-Committee on Wheels*). —I desire to quote the following paragraph from the report of the committee:

> "Certain proposed revisions in the present Standard Specifications for Wrought Steel Wheels for Passenger and Freight Service have received careful attention at the hands of the sub-committee, but it was eventually decided to recommend no changes in these specifications at this meeting."

The reason such action was taken by Sub-Committee VII of Committee A-1 was on account of the fact that the sub-committee had been working in conjunction with the Committee of the Master Car Builders' Association, and there have been several joint meetings. The sub-committee did not feel like taking up the consideration of any changes until final action of the Master Car Builders. Further, the sub-committee has done nothing in regard to standards for sizes and shapes. While this question was up at joint meeting with the Master Car Builders' Committee, it was decided best not to take action until the Master Car Builders' Association had done so. These matters will be given consideration during the coming year.

Mr. Litchfield. MR. LITCHFIELD.—I move that the proposed Standard Specifications for Wrought Solid Carbon-Steel Wheels for Electric Railway Service be referred back to the committee, inasmuch as they apply only to wheels for electric railway service, and as the American Electric Railway Engineering Association, representing the users of these wheels, is not ready to adopt any specification whatsoever. At the last convention of the American Electric Railway Engineering Association a specification was presented by its Committee on Equipment, but was not adopted by the Association as it was felt that further investigation was needed, and that it would be well for its committee to continue the study of this subject for another year and to hold further conferences with your Society. The American Electric Railway Engineering Association is an association com-

posed of railway companies which look to their engineering representatives to advise them in regard to specifications for materials, and consequently, if your Society adopts a specification drawn up by a committee on which our Association has representation, the natural inference would be that we in some measure approve of the specification. We see no reason for the immediate adoption of a specification such as you have drawn up, and therefore request that you hold the matter open for another year. **Mr. Litchfield.**

MR. STEVENSON.—As chairman of the sub-committee concerned I am opposed to this action. We have held three meetings of Committee A-1 during the last six months. The American Electric Railway Engineering Association is a member of Sub-Committee VII on Wheels. As far as I know, there were no objections made to these specifications at any of the three meetings of Committee A-1. **Mr. Stevenson.**

Mr. Litchfield has referred to experiments that are being made by his Association. Experiments similar to these are being carried on by members of this Society who are among the largest users of rolled wheels in steam railway service. There are a number of consumers on the Sub-Committee on Wheels, and I should like to hear from them as to how they feel in regard to the motion.

MR. LITCHFIELD.—I am not at present prepared to speak as to the attendance of our members at committee meetings, but I shall be glad to look up the matter and talk it over with your Secretary. I am personally of the opinion, however, that the joint work between the two associations is of considerable value, and that, regardless of any remissness on the part of our representatives, they nevertheless represent the users of these steel wheels and consequently their wishes should carry some weight. Without regard to the correctness of their ideas, it would seem that as our Association did not adopt any specification, desiring to investigate the matter further, your Society should be willing not to take any further action until our Association is ready. I again ask that you hold up this specification for another year. **Mr. Litchfield.**

MR. H. P. TIEMANN.—There is one statement of Mr. Litchfield's, in regard to the specification having been held up for **Mr. Tiemann.**

Mr. Tiemann. another year, which I think might bear a little comment. The action in Chicago, as I understand it, was to adopt this specification as a "working specification" with the idea of trying it out. In accordance with this action the specification has been published in the Year-Book of the American Electric Railway Engineering Association. It seems to us that certain requirements of the electric railway specifications which differ from those in our proposed specification are not at the present time deemed essential by the large users of steel wheels for electric service, for the reason that they have not asked for these features, and as a matter of fact, inquiries for wheels to this specification have been very rare.

The Secretary. THE SECRETARY.—I should like to call attention to a point that has been brought out frequently, in cases of this kind. If these specifications should be held up for another year, what will be the effect? Wheels will have to be bought during that time, and someone will have to make specifications governing their purchase. What reason is there for assuming that specifications under which wheels will be bought during the ensuing year are apt to be better or as good as these, which represent the joint action of men representing large consumers and large manufacturers? These specifications, as all other specifications of the Society, should be regarded as in a state of flux. Rolled wheels are a comparatively new product and the committee is looking forward very definitely, I believe, to making changes in these specifications as experience may direct. But why should not this Society put itself on record with such a specification at the present time, as being believed to be the best that can be drawn in the light of existing knowledge? Until the results of investigations now pending become available, their indications cannot be foreseen. Why should we fail to act in the meantime, especially since there is no obligation on the part of anyone to use these specifications. Any consumer who doesn't care to use them need not use them. The specifications tell their own story; their origin is fully known.

I, therefore, move you that the specifications be referred to the Society for letter ballot and that the objections voiced by the representative of the American Electric Railway Engineering Association be referred to Committee A-1 for consideration during the ensuing year. [Motion seconded.]

MR. J. O. LEECH.—I should like to ask the Secretary what the objections to these specifications are. I have heard no definite objections. Mr. Leech.

MR. C. D. YOUNG.—I believe that the committee understands what the objections of the street-railway people to these specifications are, but I should like to point out as a member of this committee, that this is a very difficult subject at the present time because steel wheels are in the course of development and if manufacturers are to have a uniform specification for their products a start must be made in the way of specifications. The vital points which street-railway people want are under consideration not only for steel wheels for electric railway service but for railroad service as well. Those items in a specification that are desirable for wheels for electric service are equally desirable for steam service. There is a sub-committee on rolled steel wheels now working on these various requirements and making progress in their investigations. Both classes of consumer also desire certain physical tests and closer tolerances than are given in the proposed specification, which subjects are also under investigation. It seems to me it would be a mistake to introduce into specifications things that we do not know will work themselves out satisfactorily in the end, but that we should rather go slow and change from year to year as we gain experience. I feel that we are not throwing over the electric-railway people any more than we are the steam-railway people in adopting a specification that has perhaps too wide tolerances. I think we should take this specification as it exists, and see what changes we shall have to make from year to year. I think it would be a mistake to postpone having in our Year-Book some specification for this product. Mr. Young.

[The motion to refer the proposed Standard Specifications for Wrought Solid Carbon-Steel Wheels for Electric Railway Service to letter ballot of the Society was then put to vote, and carried.]

DISCUSSION ON STEEL FORGING BLOOMS.

MR. G. H. WOODROFFE.—The Baldwin Locomotive Works are large users of blooms and forgings, and it does not seem to us that this specification gives us a test, or means of indicating Mr. Woodroffe.

Mr. Woodroffe. the physical soundness of blooms. I would accordingly move that the specification be referred back to the committee for further consideration.

Mr. Young. MR. YOUNG (*Chairman, Sub-Committee on Blooms*).—As I understand it, there are no definite objections to the specifications as presented except that it has been stated, I believe, that they do not go far enough in fully protecting the consumer, in that a more rigid inspection for segregation and a tension test are essential. The sub-committee that prepared these specifications has met about twelve times during the past year, and has seriously considered both of these questions. The sub-committee is unanimous in the view that a tension test specimen taken out of the bloom for forging does not represent the condition that the material will be in the finished product, and that therefore the tension-test requirement of our forging specifications will adequately protect the consumer. So far as the segregation is concerned, there is a clause in this specification which simply determines if there is any segregation present. This is as far as the sub-committee felt they could go at this time in presenting a specification to the Society. We have a sub-committee working upon this question, of which Mr. Onderdonk is chairman, with a view of offering to the Society, either next year or at some subsequent time, a more definite requirement for segregation. Each consumer has a different view as to how that segregation shall be determined. It does not seem that there is any uniformity in present practice and the sub-committee felt that it would be unwise at this time to select any one of those requirements and introduce it into a standard specification. The specification is offered merely to standardize the requirements as to chemistry and to eliminate a large number of variations in the specifications for blooms which now exist.

We feel that in offering these specifications at this time, there will be a basis for future work of the committee. The committee does not in any sense feel that its work has been completed. Its position is similar to that of the Sub-Committee on Rolled Steel Wheels. If the Society thinks that they should have complete specifications for blooms for forgings, I do not believe that requirement has been met. If, on the other hand, they desire something that will be a start in standardizing the

blooms which are being rolled, the committee feels that this is, at least, a workable specification. **Mr. Young.**

MR. R. S. MACPHERRAN.—I do not think the specifications should be adopted in an incomplete form with the idea of improving them later. I do not think we should adopt them until they are right, and will work out right. I also object to the wide range of carbon and manganese allowed in these proposed specifications. The range of 15 points in carbon and 25 points in manganese is too great. It would be difficult to meet specifications for forgings if material so uneven could be furnished to fill one and the same requirement. **Mr. MacPherran.**

MR. ROBERT JOB.—It is a well-known fact to-day that a great many of the failures which occur in forgings are due to the porosity of the metal, as has been shown, and also to the fact of pitting. The specifications which we have before us do not seem to give any method by which a considerable proportion of such defects can be detected in ordinary mill inspection. On that account it seems to me that it would be far better, as has been moved, to refer the entire question back to the committee with the recommendation that this matter be considered, and that some method be given in the specifications by which one will be enabled to detect this condition, which at the present time produces a great many failures in service and also causes a great deal of loss to the different consumers after the billets have been received apparently in good condition. **Mr. Job.**

MR. C. F. W. RYS.—I might say that if these specifications are thrown back upon the committee, forging steel will be bought as it has been up to date, simply to chemical specifications and weights. Now nobody has bought any forging blooms to these specifications yet, and I think it is worth while to have them tried out, so as to find out whether the user will get better forging billets than he has for the last ten years, when he simply bought by chemistry and weight. **Mr. Rys.**

MR. LEECH.—In regard to the wide range in carbon and manganese, I would call attention to the fact that there is provision in the specification for check analysis from the finished bloom on samples to be taken at a point half-way between the center and outside. The ranges specified were made in consideration of such check, which also guards against undue segregation. **Mr. Leech.**

Mr. Webster.

MR. W. R. WEBSTER (*Chairman, Committee A-1*).—Whether these specifications are referred back to the committee or not, I think they should appear in the Proceedings in their present form. The committee does not regard these specifications as finished by any means. It might be wise, as suggested, to put them in force to see what the result will be. On the other hand, I do not think the committee would seriously object to having them published without being adopted, so that people who might want to use them can do so. We can not expect to get perfect specifications at the start, and I do not think that these specifications cover all classes of blooms and billets that are required.

[The motion to refer the specifications back to the committee was then voted on and lost, and a motion to submit the specifications to letter ballot was adopted.]

REPORT OF COMMITTEE A-2

ON

STANDARD SPECIFICATIONS FOR WROUGHT IRON.

During the past year Committee A-2 has held meetings at Pittsburgh and Philadelphia for the purpose of considering modifications of any features of the existing specifications for wrought iron that seemed to warrant such action, and for the purpose of formulating a specification covering wrought-iron plates. The committee accordingly recommends for adoption by the Society the following changes in the present Standard Specifications for Engine-Bolt Iron, and for Refined Wrought-Iron Bars:

STANDARD SPECIFICATIONS FOR ENGINE-BOLT IRON.

1. Change Section 4 (*a*) to read as follows:

"4. For material over $1\frac{1}{4}$ sq. in. in section, a deduction of 2000 lb. per sq. in. from the tensile strength specified in Section 3 shall be made."

2. Omit Section 4 (*b*), as it will now be superfluous.

STANDARD SPECIFICATIONS FOR REFINED WROUGHT-IRON BARS.

Change Section 6 (*a*) to read as follows:

"6. (*a*) *Cold-Bend Tests.*—Cold-bend tests will be made only on bars having a nominal area of 4 sq. in. or under, in which case the test specimen shall bend cold through 180 deg. without fracture on the outside of the bent portion, around a pin the diameter of which is equal to twice the diameter or thickness of the specimen."

The committee further recommends for adoption by the Society proposed new Standard Specifications for Wrought-Iron Plates, appended to this report.

During the past year the Sub-Committee on Staybolt Iron held several meetings to consider modifications and additions to the present Standard Specifications for Staybolt Iron, giving particular consideration to the re-insertion of the vibratory test

requirements, and also to the question of a modification in the requirements for tensile strength and elongation. At a well-attended meeting held in Philadelphia on March 14, 1913, it was unanimously agreed that, inasmuch as it was understood that a vibratory test requirement would be re-inserted in the specification as soon as the committee could conduct a series of tests on existing vibratory machines and those in the course of erection to determine upon the vibratory requirements, it would be best not to consider any change in the tensile and elongation requirements of the specification until the vibratory requirements had been agreed upon, and the influence of the tensile strength and elongation upon such results had been carefully considered.

The committee, therefore, outlined an exhaustive series of tension and vibratory tests to establish such figures, but owing to delays in the completion of the vibratory machines in course of erection, the committee has been unable to make the tests outlined in time for consideration at this meeting. The committee, therefore, recommends that the present Standard Specifications for Staybolt Iron shall be continued in force for the ensuing year.

During the past year, at the request of one of the prominent railroads, a Sub-Committee on Chain Iron and Iron Chain was appointed under the chairmanship of Mr. E. B. Tilt. The sub-committee, however, was appointed too late to do any work this year, but will give matters pertaining to its field early consideration next year, with a view of offering a specification for consideration at the next annual meeting.

Respectfully submitted on behalf of the committee,

S. V. HUNNINGS,
Chairman.

J. B. YOUNG,
Secretary.

[NOTE.—The proposed amendments to the Standard Specifications for Engine-Bolt Iron and for Refined Wrought-Iron Bars were adopted by letter ballot of the Society on August 25, 1913, and the specifications as amended appear in the Year-Book for 1913. The proposed Standard Specifications for Wrought-Iron Plates were adopted August 25, 1913, and follow this report.—ED.]

AMERICAN SOCIETY FOR TESTING MATERIALS

PHILADELPHIA, PA., U. S. A.

AFFILIATED WITH THE

INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

STANDARD SPECIFICATIONS

FOR

WROUGHT-IRON PLATES.

ADOPTED AUGUST 25, 1913.

1. These specifications cover two classes of wrought-iron plates, namely: **Classes.**

Class A, as defined in Section 2 (*b*);
Class B, as defined in Section 2 (*c*).

I. MANUFACTURE.

2. (*a*) All plates shall be rolled from piles entirely free from any admixture of steel. **Process.**

(*b*) Piles for Class A plates shall be made from puddle bars made wholly from pig iron and such scrap as emanates from rolling the plates.

(*c*) Piles for Class B plates shall be made from puddle bars made wholly from pig iron or from a mixture of pig iron and cast-iron scrap, together with wrought-iron scrap.

II. PHYSICAL PROPERTIES AND TESTS.

3. The plates shall conform to the following minimum requirements as to tensile properties: **Tension Tests.**

Properties Considered	Class A.		Class B.	
	6 in. to 24 in., incl., in width.	Over 24 in. to 90 in., incl., in width.	6 in. to 24 in., incl., in width.	Over 24 in. to 90 in., incl., in width.
Tensile strength, lbs. per sq. in....	49 000	48 000	48 000	47 000
Elastic limit, lb. per sq. in.....	26 000	26 000	26 000	26 000
Elongation in 8 in., per cent.....	16	12	14	10

Modifications in Elongation.

4. For plates under $\frac{7}{16}$ in. in thickness, a deduction of 1 from the percentages of elongation specified in Section 3 shall be made for each decrease of $\frac{1}{16}$ in. in thickness below $\frac{7}{16}$ in.

Bend Tests.

5. (*a*) *Cold-bend Tests.*—The test specimen shall bend cold through 90 deg. without fracture on the outside of the bent portion, as follows: For Class A plates, around a pin the diameter of which is equal to $1\frac{1}{2}$ times the thickness of the specimen; and for Class B plates, around a pin the diameter of which is equal to 3 times the thickness of the specimen.

(*b*) *Nick-bend Tests.*—The test specimen, when nicked on one side and broken, shall show for Class A plates a wholly fibrous fracture, and for Class B plates, not more than 10 per cent of the fractured surface to be crystalline.

Test Specimens.

6. Tension and bend test specimens shall be taken from the finished plates and shall be of the full thickness of plates as rolled. The longitudinal axis of the specimen shall be parallel to the direction in which the plates are rolled.

Number of Tests.

7. (*a*) One tension, one cold-bend and one nick-bend test shall be made for each variation in thickness of $\frac{1}{8}$ in. and not less than one test for every ten plates as rolled.

(*b*) If any test specimen fails to conform to the requirements specified through an apparent local defect, a retest shall be taken; and should the retest fail, the plates represented by such test shall be rejected.

III. FINISH.

Finish.

8. The plates shall be straight, smooth and free from cinder spots and holes, and free from injurious flaws, buckles, blisters, seams and laminations.

IV. INSPECTION AND REJECTION.

Inspection.

9. (*a*) The inspector representing the purchaser shall have free entry at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the plates ordered. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the plates are being furnished in accordance with these specifications. Tests and inspection at the place of manufacture shall be made prior to shipment.

(*b*) The purchaser may make the tests to govern the acceptance or rejection of plates at his own laboratory or elsewhere. Such tests, however, shall be made at the expense of the purchaser.

REPORT OF COMMITTEE A-4

ON

HEAT TREATMENT OF IRON AND STEEL.

Committee A-4 recommends to the Society for adoption the following proposed "Recommended Practice for the Heat Treatment of Case-Hardened Carbon-Steel Objects":

PROPOSED RECOMMENDED PRACTICE FOR THE HEAT TREATMENT OF CASE-HARDENED CARBON-STEEL OBJECTS.

It is recommended that the following treatments be applied to case-hardened steel objects according to requirements:

1. When hardness of case only is desired and lack of toughness or even brittleness unimportant, the carburized articles may be quenched from the carburizing temperature, as for instance, by emptying the contents of the boxes in cold water or in oil. Both the core and the case are then coarsely crystalline.

2. In order to reduce the hardening stresses and to decrease the danger of distortion and cracking in the quenching bath, the articles may be removed from the box and allowed to cool before quenching to a temperature slightly exceeding the critical range of the case, namely, 800° to 825° C. Both the core and case remain coarsely crystalline.

3. To refine the case and increase its toughness the carburized articles should be allowed to cool slowly in the carburizing box within the furnace or outside to 650° C. or below, and should then be reheated to a temperature slightly exceeding the lower critical point of the case (in the majority of instances a temperature varying in accordance with the carbon content and thickness of the case between 775° and 825° C. will be suitable), and quenched in water, or, for greater toughness but less hardness, in oil. The objects should be removed from the quenching bath before their temperature has fallen below 100° C. This treatment is more especially to be recommended when the car-

burizing temperature has not exceeded 900° C. It refines the case but not the core.

4. To refine both the core and the case and to increase their toughness the articles should be allowed to cool slowly from the carburizing temperature to 650° C. or below and should then be (*a*) reheated to a temperature exceeding the critical point of the core which will generally be some 900° to 950° C. followed by quenching in water or in oil; and (*b*) before they have cooled below 100° C.[1] they should be reheated to a temperature slightly exceeding the lower critical point of the case (in the majority of instances a temperature varying in accordance with the carbon content and thickness of the case between 775° and 825° C. will be suitable), and again quenched in water or oil.

5. In order to reduce the hardening stresses created by quenching, the objects, as a final treatment, may be tempered by reheating them to a temperature not exceeding 200° C.

Respectfully submitted on behalf of the committee,

ALBERT SAUVEUR,
Chairman.

J. H. HALL,
Secretary.

[NOTE.—The proposed "Recommended Practice for the Heat Treatment of Case-Hardened Carbon-Steel Objects" was sent to the Secretary too late for compliance with the regulations requiring that proposed standard specifications "must be mailed by the Secretary to every member of the Society not less than four weeks before the annual meeting." Therefore it was not submitted to letter ballot of the Society.—ED.]

[1] The objects should be removed from the quenching bath before they have cooled below 100° C. in order to lessen the danger of cracking, and they should be placed in the reheating furnace while still at a temperature of at least 100° C. likewise to lessen the danger of cracking, it being inadvisable (*a*) to allow steel to cool completely in the quenching bath and (*b*) to place hardened steel in a hot furnace. Obviously, if the furnace is cold the hardened steel may likewise be cold when placed in it for reheating.

REPORT OF COMMITTEE A-8

ON

STANDARD SPECIFICATIONS FOR COLD-DRAWN STEEL.

The committee has held a number of meetings and has carried out extensive tests on materials manufactured for use in automatic screw machines. Up to this time the committee has not attempted to draft specifications for any material other than that which it would designate as automatic screw stock. Two specifications are submitted herewith, entitled, "Tentative Specifications for Cold-Drawn Steel: Bessemer Automatic Screw Stock," and "Tentative Specifications for Cold-Drawn Steel: Open-hearth Automatic Screw Stock."

The committee recommends that these specifications be published in the Proceedings as trial specifications, with a view of giving the material called for a very thorough trial in as many services as possible. It should be understood that the material is intended primarily for use in automatic screw machines where very high cutting speeds are desirable; and since it shows a relatively small ductility on physical test, it is not suited for service where a ductile material is required.

The committee requests that parties purchasing material in accordance with these specifications keep a record of the results which they obtain, with a view of furnishing data to the committee so that eventually the specifications may either be modified as may be found necessary, or adopted as standard if found satisfactory.

Respectfully submitted on behalf of the committee,

C. E. SKINNER,
Chairman.

AMERICAN SOCIETY FOR TESTING MATERIALS

PHILADELPHIA, PA., U. S. A.

AFFILIATED WITH THE

INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

TENTATIVE SPECIFICATIONS FOR COLD-DRAWN STEEL.

BESSEMER AUTOMATIC SCREW STOCK.

1. The material desired under these specifications is a free-cutting steel of any specified section suitable for high-speed screw machine work, leaving a smooth finish after machining. **Material Desired.**

I. MANUFACTURE.

2. The steel shall be made by the Bessemer process, and shall be cold-rolled or cold-drawn or turned to size. **Process.**

II. CHEMICAL PROPERTIES AND TESTS.

3. The steel shall conform to the following requirements as to chemical composition: **Chemical Composition.**

Carbon	0.08 – 0.16 per cent
Manganese	0.60 – 0.80 "
Phosphorus	0.09 – 0.13 "
Sulphur	0.075 – 0.15 "

4. Samples for analysis shall be taken by machining off the entire cross-section of the bar, or by drilling parallel to the axis **Test Samples.**

of the bar at any point midway between the center and surface with a drill not under $\frac{1}{2}$ nor over $\frac{3}{4}$ in. in diameter. Samples shall be clean, free from oil, uniformly fine and well mixed.

III. DIMENSIONS.

Permissible Variations.

5. The variation from the specified diameter, or distance between parallel faces, and the allowable eccentricity shall not exceed the following limits:

PERMISSIBLE VARIATIONS.

Diameter.	Over-size.	Under-size.	Eccentricity.
Up to and including 0.3 in.....	0	1% of diameter	0.5% of diameter
Over 0.3 in. to and including 1 in.	0	0.003 in.	0.0015 in.
Over 1 in. to and including $2\frac{1}{2}$ in.	0	0.004 "	0.0020 "
Over $2\frac{1}{2}$ in.....	0	0.005 "	0.0025 "

IV. FINISH.

Finish.

6. The material shall be free from injurious defects and shall have a bright smooth surface.

V. INSPECTION AND REJECTION.

Inspection.

7. The manufacturer shall afford the inspector representing the purchaser, free of cost, all reasonable facilities to satisfy him that the material is being furnished in accordance with these specifications.

Rejection.

8. Material which fails to conform to the above specifications will be rejected, and the manufacturer shall be notified.

AMERICAN SOCIETY FOR TESTING MATERIALS

PHILADELPHIA, PA., U. S. A.

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INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

TENTATIVE SPECIFICATIONS

FOR

COLD-DRAWN STEEL.

OPEN-HEARTH AUTOMATIC SCREW STOCK.

Material Desired.

1. The material desired under these specifications is a free-cutting steel of any specified section suitable for high-speed screw machine work, leaving a smooth finish after machining.

I. MANUFACTURE.

Process.

2. The steel shall be made by the open-hearth process, and shall be cold-rolled or cold-drawn or turned to size.

II. CHEMICAL PROPERTIES AND TESTS.

Chemical Composition.

3. The steel shall conform to the following requirements as to chemical composition:

Carbon	0.15 – 25.0 per cent
Manganese	0.60 – 0.90 "
Phosphorus	not over 0.05 "
Sulphur	0.075 – 0.12 "

Test Samples.

4. Samples for analysis shall be taken by machining off the entire cross section of the bar, or by drilling parallel to the axis

of the bar at any point midway between the center and surface with a drill not under $\frac{1}{2}$ nor over $\frac{3}{4}$ in. in diameter. Samples shall be clean, free from oil, uniformly fine and well mixed.

III. DIMENSIONS.

Permissible Variations.

5. The variation from the specified diameter, or distance between parallel faces, and the allowable eccentricity shall not exceed the following limits:

PERMISSIBLE VARIATIONS.

Diameter.	Over-size.	Under-size.	Eccentricity.
Up to and including 0.3 in.....	0	1% of diameter	0.5% of diameter
Over 0.3 in. to and including 1 in...	0	0.003 in.	0.0015 in.
Over 1 in. to and including $2\frac{1}{2}$ in...	0	0.004 "	0.0020 "
Over $2\frac{1}{2}$ in.....	0	0.005 "	0.0025 "

IV. FINISH.

Finish.

6. The material shall be free from injurious defects and shall have a bright smooth surface.

V. INSPECTION AND REJECTION.

Inspection.

7. The manufacturer shall afford the inspector representing the purchaser, free of cost, all reasonable facilities to satisfy him that the material is being furnished in accordance with these specifications.

Rejection.

8. Material which fails to conform to the above specifications will be rejected, and the manufacturer shall be notified.

DISCUSSION

Mr. C. D. Young.—It may be of interest to some of the users of this material to know of the experience the Pennsylvania Railroad Co. has had with it. We were using Bessemer stock in automatic machines and found it very popular with the operators. It cuts a beautiful thread, with a very clean finish and therefore makes a very desirable material for automatic machines. But if the parts were subjected to shock or stress, we found that in a very short time they would crack, due, probably, to the high phosphorus in the steel. We then resorted to open-hearth stock, which is represented by the second specification, and which, in chemical terms, seems very good to me, and found it was very unpopular with the tool operators. It was very difficult to keep the dies and cutters sharp so as to operate the machines to their highest efficiency, but by insistence on the proper care of the tools, we were able to work this stock. So far as my knowledge goes at this time, we have had no trouble whatsoever with the material in service. I would caution everybody against using Bessemer stock where it is subject to shock of any kind, and, generally speaking, the threaded portions will be subjected to that sort of service. **Mr. Young.**

Mr. S. S. Voorhees.—I should like to ask Mr. Capp why phosphorus and sulphur in both these types of steel are given minimum values in these specifications. **Mr. Voorhees.**

Mr. J. A. Capp.—It has been the experience of makers of this type of steel, and the users of it in large quantities, that the unusually high sulphur content materially adds to its machining qualities, giving what might be called a brittle chip. **Mr. Capp.**

In respect to what Mr. Young has said, it might be well to add that the committee has not offered these specifications with recommendations to use this sort of steel for any other purpose than for its free machining qualities. We have purposely avoided saying anything about the physical characteristics of the steel, but it is obvious that the Bessemer steel will probably be relatively brittle as compared with the open-hearth steel.

REPORT OF COMMITTEE A-10

ON

HARDNESS TESTS.

Under the inspiration of several papers upon hardness tests presented before the Society in recent years, a resolution was passed at the annual meeting in 1911 directing the Executive Committee to consider the advisability of creating a committee upon the subject. After considering the matter the Executive Committee in the fall of that year decided to establish such a committee and designated a provisional membership.

The first meeting of this provisional membership was held in New York during the Congress of The International Association for Testing Materials, in September, 1912, and a partial organization was effected by the election of a chairman.

It was decided that the committee should apply itself to classifying and defining the different kinds of hardness, such as: penetration hardness (Brinell), cutting hardness, elastic hardness (Shore), mineralogical hardness, file hardness, hardness against wear, Keep's hardness, Jaggar's hardness, etc.

It was also decided that in preparation for the more serious work of the committee, some effort be made toward the systematic collection and classification of data and the preparation of a bibliography of the subject of hardness measurements.

On account of the secondary nature of the subject and the distribution of the membership, it has thus far been impossible to obtain since last fall a satisfactory meeting of the committee.

The major part of the work must of necessity be conducted by correspondence, at best a very slow process. Notwithstanding this condition it is hoped and believed that during the next year sufficient can be accomplished to enable the committee to present at the next annual meeting of the Society some material of real value.

The membership as at present constituted consists of technical men engaged very largely in consulting and advisory

work. Numerous attempts have been made to secure the assistance upon the committee of members representing the consuming interests in which such measurements find actual application. It is hoped that during the next year at least two such members can be added to advise the committee upon the questions of application and use.

Respectfully submitted on behalf of the committee,

D. E. DOUTY,
Chairman.

REPORT OF COMMITTEE B-1

ON

STANDARD SPECIFICATIONS FOR COPPER WIRE.

Since making its last report, no new work has been undertaken by Committee B-1, and substantially the only modifications of the specifications already adopted as standard are those made necessary by reason of the proposed international agreement on a standard for the conductivity of copper.

It will be recalled that at the last annual meeting the American Institute of Electrical Engineers, and the International Electro-Technical Commission, recommended that Committee B-1 adopt as the base of their specifications for copper wire, the standard of conductivity which is recommended by the International Electro-Technical Commission, and which will come up for adoption at the meeting of that commission in September, 1913. The value of the proposed international standard is approximately one-sixth of one per cent lower than the value which has been commonly accepted in the United States during the past several years.

At the annual meeting in 1912, after conference between the representative of the American Institute of Electrical Engineers and the International Electro-Technical Commission, and members of Committees B-1 and B-2, it was agreed that the proposed action with respect to the international standard for conductivity be postponed until such standard had actually been agreed upon internationally, and it has been the suggestion of Committee B-1 that there be set by agreement some fixed date upon which the change from the present accepted standard for conductivity to the new international standard is to become effective. For instance, January 1, 1914, is suggested.

Committee B-1 has at very considerable length discussed the matter of specifications for resistivity or conductivity of copper wire, and the conclusion reached is a reaffirmation of the opinion expressed by the committee in its first report[1] in 1909,

[1] *Proceedings*, Am. Soc. Test. Mats., Vol. IX, p. 309 (1909).

to the effect that it is preferable to express the requirements included in specifications in terms of directly measurable quantities, rather than by reference to some other quantity whose standard value is fixed only by agreement. There is really no more reason for the use of the arbitrary term "conductivity" to express electrical resistance than there is for the employment of arbitrary gage numbers to express dimensions. The committee, therefore, has unanimously voted to recommend that all reference to conductivity be removed from the specifications, and that the requirements instead be stated solely as the maximum rejection limits to the resistivity. This action, in the opinion of the committee, is the more necessary because the committee has felt it both unnecessary and undesirable to lower the present standard of quality of copper wire, and if we were to base the specifications on the proposed international standard for conductivity, it would require either that the standard be lowered, or that the rejection limit be set at an awkward figure; for instance, 98.17 per cent for soft annealed wire.

Recognizing the great desirability and importance of having the same standard adopted by all the technical bodies, Committee B-1 has also unanimously agreed to recommend changing the specific gravity specified as standard in the copper wire specifications to the value which has been adopted by the American Institute of Electrical Engineers, and which is recommended for adoption by the International Electro-Technical Commission, namely, 8.89 at 20° C. This will supersede the value of 8.90 at 20° C., which has been the standard heretofore in the specifications of this Society. While Committee B-1 formally recommends this change in the interest of uniformity, it desires to place on record the opinion that the value is too low. The degree of purity of copper commercially available for manufacture into wire for electrical use has increased during the last several years, and records of the refiners of copper, and of the producers of copper wire, show that whereas the value 8.89 was, perhaps, a reasonable average several years ago, it is to-day below the average of commercial copper. Committee B-1 will make recommendation, through Committee E-2 on Electrical Standards, to the Institute of Electrical Engineers and to the International Electro-Technical Commission, that data be

collected upon which to base a recommendation for a new value for standard specific gravity for use in specifications, etc., when the matter may properly be brought up for consideration at the next meeting of the International Electro-Technical Commission three years hence.

Work has been continued by the joint committee made up of representatives of the Power Committee of the American Electric Railway Engineering Association, and of Committee B-1, on the preparation of jointly acceptable specifications for trolley wire. A recommendation was made by the committee representing the American Electric Railway Engineering Association, but after mature deliberation Committee B-1 was unable to agree to the proposition, which was referred back to the joint committee for further consideration. It is hoped that a satisfactory agreement upon joint specifications for trolley wire may be reached in the course of another year.

Attention has been called to the fact that the requirements covering cable or strand are stated more definitely in the Standard Specifications for Medium Hard-Drawn Copper Wire than in those for Hard-Drawn Copper Wire, and the committee recommends the substitution of the requirements as stated in the former specifications for those in the latter.

Committee B-1 unanimously recommends amendments to the three specifications for copper wire for which they are responsible, as follows:

STANDARD SPECIFICATIONS FOR HARD-DRAWN COPPER WIRE.

1. Amend Section 5 by substituting 8.89 for 8.90, and add "at 20° C."

2. Amend Section 9 by substituting "resistivity" for "conductivity."

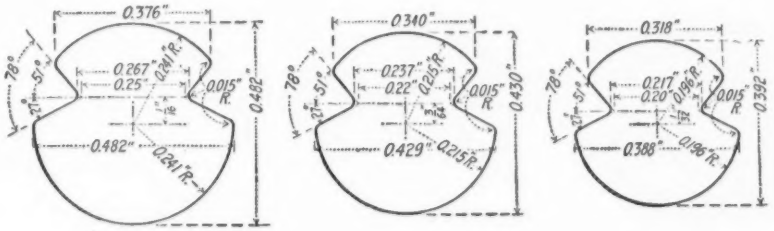
3. Amend Section 13 by substituting "resistivity" for "conductivity."

4. Amend Section 15 by substituting "resistivity' for "conductivity."

5. Amend requirements under sub-title "Hard-Drawn Copper-Wire Cable or Strand," by substituting for Sections 17,

18, 19 and 20, Sections 11, 12 and 13 from the Specifications for Medium Hard-Drawn Copper Wire, renumbering them respectively 17, 18 and 19.

6. The following new cuts of the standard American sections of grooved trolley wire are to replace those now in the specifications, the cuts being to enlarged scale, permitting the inclusion of dimensions which have been found essential.



211 600 C.M. Wire. 168 100 C.M. Wire 133 200 C.M. Wire

STANDARD SPECIFICATIONS FOR MEDIUM HARD-DRAWN COPPER WIRE.

1. Amend Section 5 by substituting 8.89 for 8.90 and adding "at 20° C."

2. Amend Section 9 by substituting "resistivity" for "conductivity."

STANDARD SPECIFICATIONS FOR SOFT OR ANNEALED COPPER WIRE.

1. Correct Section 4, Paragraph (*a*), by omitting "of the" between "limiting" and "dimensions" in line 9, making the sentence read: "The table also states the limiting dimensions of the coils, reels, and spools on which the wire may be shipped."

2. Amend Section 5 by substituting 8.89 for 8.90, and adding "at 20° C."

3. Amend Section 8 by substituting "resistivity" for "conductivity."

The following modifications are also made in the explanatory notes accompanying the several specifications. It will not be

necessary to refer them to letter ballot of the Society, since they are not formally a part of the specifications.

MODIFICATIONS OF EXPLANATORY NOTES ACCOMPANYING SPECIFICATIONS ON COPPER WIRE.

Explanatory Notes on Specifications for Hard-Drawn Copper Wire.—1. Substitute the following for Section 5:

"The specific gravity of copper was formerly standardized in these specifications at 8.90. The value has been changed to 8.89, since that is the value adopted as standard by the American Institute of Electrical Engineers, and recommended for adoption by the International Electro-Technical Commission."

2. For Section 9, on Conductivity, substitute the following:

"Electric conductivity was formerly expressed as a percentage, on the basis of a determination made by Matthiessen about 1865, of the electric resistivity of supposedly pure copper. Since that time the methods of refining copper have advanced, so that it is not uncommon to find copper of over 100 per cent conductivity on the Matthiessen basis. There has heretofore not been international agreement on the electric resistivity of copper to be considered the standard for the expression of conductivity. While it is to be expected that an international agreement upon a standard for the resistivity of copper equal to 100 per cent conductivity, will be adopted by the International Electro-Technical Commission in September, 1913, it has been deemed preferable to express the requirements in standard specifications in the terms of quantities directly measurable, rather than by reference to some quantity whose standard value is the subject of agreement only. The use of the arbitrary term "conductivity" has no more warrant than the employment of arbitrary gage numbers. Therefore, in these specifications the requirements are stated as the maximum rejection limits to the resistivity.

"For the convenience of those who are accustomed to express resistivity in any one of the several more or less common units, the following table of equivalents has been prepared, giving the resistivity of copper at 20° C.:

900.77 lb. per mile-ohm is equal to:

0.15775 ohms per meter-gram,
1.7745 microhms per centimeter-cube,
0.69863 microhms per inch-cube,
10.674 ohms per mil-foot.

910.15 lb. per mile-ohm is equal to:

0.15940 ohms per meter-gram,
1.7930 microhms per centimeter-cube,
0.70590 microhms per inch-cube,
10.785 ohms per mil-foot.

3. Renumber present Section 19 as Section 17, and insert it between Sections 16 and 18.

Explanatory Notes on Standard Specifications for Medium Hard-Drawn Copper Wire.—1. Substitute for present Section 5, the matter given above for Section 5 under Notes on Specifications for Hard-Drawn Copper Wire.

2. Substitute for present Section 9, on Conductivity, the matter given above for Section 9 under Notes on Specifications for Hard-Drawn Copper Wire, except that the table of equivalents must be as follows:

896.15 lb. per mile-ohm is equal to:

0.15694 ohms per meter-gram,
1.7654 microhms per centimeter-cube,
0.69504 microhms per inch-cube,
10.619 ohms per mil-foot.

905.44 lb. per mile-ohm is equal to:

0.15857 ohms per meter-gram,
1.7837 microhms per centimeter-cube,
0.70224 microhms per inch-cube,
10.729 ohms per mil-foot.

Explanatory Notes on Standard Specifications for Soft or Annealed Copper Wire.—1. For present Section 5, substitute the matter given above for Section 5 under Notes on Specifications for Hard-Drawn Copper Wire.

2. For present Section 8, on Conductivity, substitute the matter given above for Section 9 under Notes on Specifications for Hard-Drawn Copper Wire, except that the table of equivalents must be as follows:

891.58 lb. per mile-ohm is equal to:

0.15614	ohms per meter-gram,
1.7564	microhms per centimeter-cube,
0.69150	microhms per inch-cube,
10.565	ohms per mil-foot.

Respectfully submitted on behalf of the committee,

J. A. CAPP,
Chairman.

[NOTE.—The proposed amendments in the Standard Specifications for Hard-Drawn Copper Wire, for Medium Hard-Drawn Copper Wire, and for Soft or Annealed Copper Wire, were adopted by letter ballot of the Society on August 25, 1913, and the specifications as amended appear in the Year-Book for 1913.—ED.]

DISCUSSION.

MR. NORMAN LITCHFIELD (*by letter*).—*Specifications for Trolley Wire.*—Conferences on the preparation of mutually acceptable specifications for trolley wire were continued during the past year by the joint committee made up of representatives of the Committee on Power Distribution of the American Electric Railway Engineering Association and of Committee B-1. A specification was prepared by the joint committee; Committee B-1 decided, however, that it could not consistently adopt the proposed specification in the present standard Specifications for Hard-Drawn Copper Wire, but believed that a specification should be drawn solely to cover trolley wire and stand by itself as the joint specification for trolley wire of the American Society for Testing Materials and the American Electric Railway Engineering Association, instead of being written into the general hard-drawn wire specification. In view of this action, the Engineering Association offers its further services in conference with the American Society for Testing Materials during the coming year, to the end that a standard specification shall be drawn up and adopted as early as possible. The Committee on Power Distribution will therefore so report to the Convention of the Engineering Association in October. Mr. Litchfield.

Sections of Grooved Trolley Wire.—The Engineering Association wishes to urge the adoption as standard of the sections of grooved trolley wire recommended by Committee B–1 in its report. These sections coincide in all respects with those adopted as standard by the Engineering Association at its convention last year.

REPORT OF COMMITTEE B-2

ON

NON-FERROUS METALS AND ALLOYS.

For the time being it has been found convenient to divide the work up amongst four sub-committees, as follows:

I. Pure Metals in Ingot Form; W. H. Bassett, Chairman.
II. Wrought Metals and Alloys; W. R. Webster, Chairman.
III. Copper Casting Alloys—Brass and Bronze; T. D. Lynch, Chairman.
IV. White Metals—Tin, Lead and Zinc Base; G. H. Clamer, Chairman.

Sub-Committee I on Pure Metals in Ingot Form.—The work of Sub-Committee I for the year consisted in the revision of specifications for copper and resulted in two proposed standard specifications, which are presented to the Society for consideration and adoption, and which are designed to replace the present standard specifications for Copper Wire Bars, Cakes, Slabs. Billets, Ingots, and Ingot Bars:

(*a*) For Lake Copper Wire Bars, Cakes, Slabs, Billets, Ingots, and Ingot Bars;
(*b*) For Electrolytic Copper Wire Bars, Cakes, Slabs, Billets, Ingots, and Ingot Bars.

These specifications are appended to this report.

The question of arsenical copper has been thoroughly discussed and the sub-committee felt that this could best be covered by the following unanimous report:

The Classification of American Copper.

The American copper production has been classified, after a careful consideration of the present trade conditions, into (*a*) Electrolytic, (*b*) Lake, and (*c*) Casting. Specifications were drawn up for what was virtually electrolytic copper two years ago, and adopted by the Society August 21, 1911. A further

step has been taken this year by submitting a revised electrolytic specification, with a definite limitation to electrolytic copper, the clauses in the former specification intended to include certain classes of Lake copper having been deleted. At the same time a separate specification for Lake copper in two main classes has been drafted after discussion with those most intimately connected with its production, sale and use. While this specification is not entirely satisfactory in that a geographical restriction is by the nature of things not a true factor in determining value, it is believed that such a recognition of the trade conditions as they exist is necessary to a working specification, and that it will be some years before a more rational classification can be imposed. The situation regarding casting copper was carefully canvassed and at first it was thought possible to subdivide this into virgin and reclaimed copper, but no way has been found to reconcile the great differences in composition of casting copper offering in the American market with the corresponding values and uses, which, while not directly part of a specification, have much to do with the acceptability of its clauses. Your subcommittee, therefore, decided that at the moment a statement of the conditions would be wiser than a formal specification.

After electrolytic and Lake copper have been disposed of, there are three sources of more or less impure copper which are marketed as "casting": (*a*) fire-refined copper from virgin sources, (*b*) copper electrolytically produced by deposition from impure liquors, and (*c*) copper reclaimed from secondary sources.

The virgin casting copper corresponds in a general way to the fine copper produced in many parts of the world before the days of electrolysis. Its principal characteristics are a resistivity too great for modern electrical uses and small quantities of more or less innocuous impurities, the copper contents being quite high—99.80 per cent or over. The old fire processes, while yielding a high-grade copper, did not satisfactorily separate the silver and gold values which generally are found in copper deposits, and to-day as soon as a few dollars' worth of silver and gold per ton of copper are present, electrolytic refining becomes an economic necessity. The number of deposits which yield a copper suitable for fire refining is, therefore, very limited and there are but very few well-known producers of such material, although

the quantity produced is considerable, as the particular deposits are quite extensive.

Lake copper, which has but little silver and practically no gold associated with its deposits, is removed from the class just considered, by the fact that the mineral carries copper in the native or metallic state and practically free from all impurities but arsenic.

The second source of casting copper—electrolytic precipitation from impure liquors—is very irregular. In electrolytic refining, a certain proportion of the output, varying from nothing to two per cent, has to be recovered by use of insoluble anodes, due to chemical solution of part of the copper as distinguished from electrochemical solution. As copper electrolytes invariably carry arsenic and other impurities, a contaminated cathode is produced on account of the high working voltage—two volts or over—of such a tank. At one time this material was made into casting copper, but as it was difficult to market on account of the quantity and grade—copper varying from 97.5 to 99.5 per cent—it has largely been suppressed, by re-refining, crystallization as bluestone, or in other ways.

The third source of casting copper—reclaimed copper—is large in quantity. In quality it is generally an alloy carrying tin and nickel as the main impurities and of no fixed composition. An ordinary average would be about 99.25 per cent copper, but 98.5 per cent would not be unusual. The impurities, however, may be a distinct advantage in foundry work, as a little tin generally improves the properties of the castings. The source of this product is mainly miscellaneous copper-bearing material derived from the manufacture of brass and bronze. This is usually collected by junk men and sold to the refiners, who largely eliminate the zinc, lead and iron which such waste carries.

The clean brass and copper scrap from large mills working these metals do not find their way into this secondary trade, as they are readily worked up into new material by the original melters. There are many small smelters and a few large ones dealing in this miscellaneous foul scrap and their output is so variable that any comprehensive specification seems impossible. The larger concerns have brands which they protect by maintaining their individual characteristics reasonably constant,

however much the particular brands may differ among themselves.

Summarizing, about all that can be said of casting copper to-day is that it is not reasonable to expect either low resistivity or any considerable ductility from such material; as its name implies it is exclusively a foundry copper. The copper contents are very variable; better known brands run in general over 99 per cent and in some cases of virgin copper an assay of 99.9 per cent is regularly maintained. As long as the copper is clean, free from slag or dirt, and shows good fluidity when melted, but little objection can be made to the particular impurities which may be present.

From what has been said, it will be seen that it is impossible to draw up a specification which can be acceptable at the same time to all of even the larger producers and consumers of what is nevertheless a distinct class of American copper. If the consumer is interested in getting certain results possibly connected with the particular impurities present, he should familiarize himself with the assay of the brands with which he has had success and insist upon uniform delivery. If he is buying casting copper at a price far below electrolytic, he must realize that the copper contents must be low or it would have paid the producer to have had the copper electrolytically refined. A great deal of the consumption is by small brass foundries where testing facilities are very limited, and, consequently, specifications are not likely to be given serious attention.

Sub-Committee II on Wrought Metals and Alloys.—Sub-Committee II regrets that it has as yet been unable to formulate any specifications for submission.

Proper specifications demand a clear understanding of the requirements of use, accurate definitions of the qualities necessary to meet requirements, and rational tests for determining these qualities. Such a solution necessitates wider and more accurate knowledge than now is available either from producers or consumers.

Partial specifications covering certain minor requirements could have been presented, but it has not been considered that the presentation of specifications incomplete as to the major points would serve any useful purpose at this time.

Sub-Committee III on Copper Casting Alloys.—Sub-Committee III confined its work to the revision of the present specifications for manganese bronze, and suggested certain changes in regard to composition. On account of the fact that the present method of taking test specimens is not satisfactory, it was decided to let the present specification stand and refer the whole specification back to the sub-committee for complete revision.

Sub-Committee IV on White Metals.— Sub-Committee IV held two meetings during the year. At the first meeting a certain line of work was laid out covering five alloys, which represent the most widely used babbitt metals in service. At the second meeting the work of the various members of the committee was reported.

The series of alloys investigated were as follows:

	TIN.	ANTIMONY.	COPPER.	LEAD.
No. 1.....	89.00	7.00	4.00	.....
No. 2.....	83.33	8.33	8.33	.....
No. 3.....	50.00	12.00	1.00	37.00
No. 4.....	7.00	17.00	....	76.00
No. 5.....	....	10.00	....	90.00

It was decided that the committee's work should, for the present, be confined to the study of the properties of these various alloys, and the determining of the most satisfactory method of sampling and analyzing. With this end in view, analyses were made by five members of the committee, all using the methods which were standard in their respective laboratories. The analyses were to be made on samples taken by saw-cutting at right angles to the length of the bar, at points one inch from each end and in the middle. These sawings were to be thoroughly mixed. Unfortunately, two members of the committee overlooked the instructions relative to the sampling, and took their samples by drilling and without reference to the location of the holes. In these two cases the analyses, on at least two of the samples, showed quite a wide variation from the aimed-at formulas. There was also probably sufficient difference between the results obtained by the other members to warrant the work being repeated. The results are given in Table I.

TABLE I.—RESULTS OF TESTS ON ALLOYS.

ALLOY NO. 1.

	Tin, per cent.	Antimony, per cent.	Copper, per cent.	Lead, per cent.	Other Constituents, per cent.
Theoretical	89.00	7.00	4.00	....	.....
G. H. Clamer	88.70	7.20	3.40	0.58	.....
T. D. Lynch	89.00	7.40	3.40	0.20	.....
H. E. Smith	88.53	7.11	3.93	0.19	Arsenic.... 0.05
G. W. Thompson	88.57	7.09	3.92	0.38	Arsenic.... 0.09
W. M. Corse[1]	88.52	7.06	3.70	0.21	Zinc..... 0.26 Iron..... 0.13

ALLOY NO. 2.

Theoretical	83.33	8.33	8.33	....	.....
G. H. Clamer	83.40	8.30	7.50	0.65	.....
T. D. Lynch	82.40	9.00	8.40	0.20	.....
H. E. Smith	82.65	8.51	8.34	0.28	Arsenic.... 0.06
G. W. Thompson	82.56	8.54	8.44	0.35	Arsenic.... 0.09
W. M. Corse[1]	83.00	8.34	8.33	0.27	Iron..... 0.13

ALLOY NO. 3.

Theoretical	50.00	12.00	1.00	37.00	.....
G. H. Clamer	50.00	12.00	0.60	37.28	.....
T. D. Lynch	51.00	12.00	0.50	36.50	.....
H. E. Smith	50.07	11.72	0.80	36.96	Arsenic.... 0.02
G. W. Thompson	49.75	11.36	0.81	37.96	Arsenic.... 0.09
W. M. Corse[1]	49.86	11.68	0.84	37.54	.....

ALLOY NO. 4.

Theoretical	7.00	17.00	....	76.00	.....
G. H. Clamer	7.20	17.10	0.08	75.51	.....
T. D. Lynch	7.30	18.30	....	73.30	.....
H. E. Smith	7.14	17.06	0.02	75.55	Arsenic.... 0.01
G. W. Thompson	7.20	16.85	0.04	76.06	Trace
W. M. Corse[1]	5.91	15.44	....	78.56	.....

ALLOY NO. 5.

Theoretical	....	10.00	....	90.00	.....
G. H. Clamer	0.05	10.00	0.16	89.66	.....
T. D. Lynch	0.00	10.50	....	89.00	.....
H. E. Smith	....	9.91	0.01	89.90	Arsenic.... 0.02
G. W. Thompson	....	9.94	Trace	90.04	Trace
W. M. Corse[1]	....	9.55	....	90.40	.....

The Brinell hardness tests and the compression tests which were made were equally unsatisfactory, and it was found that a standard method of making these tests would have to be formulated. Furthermore, it was thought desirable to rearrange

[1] On comparing results of analyses, it was found that in two cases where all the samples had been taken by drilling, the results were quite out of agreement with the other results reported. This was especially true of the lead-base babbitts. Although our ingots had all been remelted at least once to make test pieces for compression samples, it was decided that

the series of alloys in respect to their hardness from 1 to 5, so that the five alloys would satisfactorily cover the range for all requirements, thus eliminating the thousands of slight variations which are at present made in the five standard types suggested, for no particular reason or advantage. It was thought that a satisfactory rearrangement of the series would be as follows:

	TIN.	ANTIMONY.	COPPER.	LEAD.
No. 1.....	89.00	7.00	4.00	.....
No. 2.....	83.33	8.33	8.33	.....
No. 3.....	50.00	15.00	2.00	33.00
No. 4.....	5.00	15.00	....	80.00
No. 5.....	....	10.00	....	90.00

Cooling curves of the various alloys were made by Mr. G. W. Thompson and determinations of melting points and complete liquidation points. Microphotographs were made and also Brinell hardness tests at atmospheric temperature and at 100° C. Hammer tests were made by Mr. T. D. Lynch, the results of which are given in a paper entitled "Study of Bearing Metals and Methods of Testing" to be presented at this meeting.[1]

we would take sawings from the remains of the cylindrical pieces described in the previous report and run analyses on them. The results obtained on the remelted material, together with the previous results, follow:

Sample No.	Method of Sampling.	Tin, per cent.	Antimony, per cent.	Copper, per cent.	Lead, per cent.	Iron, per cent.
1	Drillings from Ingot..	88.52	7.06	3.70	0.21	0.13 (Zn 0.26)
	Sawings from Remelt.	88.00	7.27	4.05	0.28	0.42
2	Drillings from Ingot..	83.00	8.34	8.33	0.27	0.13
	Sawings from Remelt.	82.92	8.31	8.34	0.26	0.14
3	Drillings from Ingot..	49.86	11.68	0.84	37.54	....
	Sawings from Remelt.	49.66	11.56	0.84	37.80	0.09
4	Drillings from Ingot..	5.91	15.44	....	78.56	trace
	Sawings from Remelt.	6.94	17.00	....	75.86	0.19
5	Drillings from Ingot..	.....	9.55	....	90.40	....
	Sawings from Remelt.	.....	9.88	....	90.10	0.09

As these analyses are made on remelted material, it is, of course, impossible to compare them directly with the results reported by other members of the committee. It is, however, worth noticing that the lead-base samples Nos. 4 and 5 are now in much closer agreement with the theory and other results reported. It may also be pointed out that the iron content has increased in all cases in the remelted material.

Particular attention should be called to the fact that no zinc is reported in sample No. 1, remelted material. The first report gave 0.26 per cent present in the ingot, which was evidently an error, as we have since found that the zinc came from the glassware used.

W. M. CORSE.

[1] Pp. 699-711.

As a standard method of sampling and analysis is of prime importance, it is the first question which should be settled by the committee, and in this connection the committee has asked the cooperation of the Bureau of Standards, and will produce a new series of samples, all taken in precisely the same manner and in accordance with an agreed-upon method, so that it is hoped by next year that the work will have progressed to such a point that recommendations can be made for satisfactory specifications covering babbitt metals, as follows:

1. Recommendation of five, or perhaps six or seven standard formulas, which will cover the entire range of requirements for babbitt metals, with variable limits on each constituent, and stipulation of maximum impurities;
2. Standard methods of sampling;
3. Standard method of analysis;
4. Recommendation for proper heat treatment and method of manufacture;
5. Physical tests, which will show whether the alloy has been properly prepared and subjected to correct heat treatment.

The work of Committee B-2 will be continued along the present lines and new sub-committees formed, as necessity arises, to take up new work of which there is an abundance.

Respectfully submitted on behalf of the committee,

WILLIAM CAMPBELL,
Chairman.

[NOTE.—The proposed Standard Specifications for (*a*) Lake Copper Wire Bars, Cakes, Slabs, Billets, Ingots, and Ingot Bars, and (*b*) Electrolytic Copper Wire Bars, Cakes, Slabs, Billets, Ingots, and Ingot Bars, were adopted by letter ballot of the Society on August 25, 1913, and follow this report.—ED.]

AMERICAN SOCIETY FOR TESTING MATERIALS

PHILADELPHIA, PA., U. S. A.

AFFILIATED WITH THE

INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

STANDARD SPECIFICATIONS

FOR

LAKE COPPER WIRE BARS, CAKES, SLABS, BILLETS, INGOTS, AND INGOT BARS.

ADOPTED AUGUST 25, 1913.

Definition. 1. In order to be classed as Lake, copper must originate on the northern peninsula of Michigan, U. S. A.

Marks. 2. All wire bars, cakes, slabs, and billets shall be stamped with the maker's brand and furnace charge mark. Ingots and ingot bars shall have a brand stamped or cast in, but need have no furnace charge mark.

Lots. 3. The refiner shall arrange carloads or lots so that as far as possible each shall contain pieces from but one furnace charge, in order to facilitate testing by the user.

Resistivity. 4. (*a*) *Low Resistance Lake.*—Lake copper offered for electrical purposes, whether fire or electrolytically refined, shall be known as "Low Resistance Lake."

Low Resistance Lake wire bars shall have a resistivity not to exceed 0.15535 international ohms per meter-gram at 20° C. (annealed). All ingots and ingot bars shall have a resistivity not to exceed 0.15694 international ohms per meter-gram at 20° C. (annealed).

Cakes, slabs, and billets shall come under the ingot classification, except when specified for electrical use at time of purchase; in which case wire-bar classification shall apply.

(*b*) ***High Resistance Lake.***—Lake copper having a resistivity greater than 0.15694 international ohms per meter-gram at 20° C. shall be known as "High Resistance Lake."

Metal Contents.

5. (*a*) Low Resistance Lake copper shall have a purity of at least 99.880 per cent as determined by electrolytic assay, silver being counted as copper.

(*b*) High Resistance Lake copper shall have a purity of at least 99.880 per cent, copper, silver, and arsenic being counted together. The arsenic content of High Resistance Lake copper, when required for special purposes, shall be the subject of agreement at time of purchase.

Physical Standard.

6. Wire bars, cakes, slabs, and billets shall be substantially free from shrink holes, cold sets, pits, sloppy edges, concave tops and similar defects in set or casting. This clause shall not apply to ingots or ingot bars, in which case physical defects are of no consequence.

Weight of Individual Pieces.

7. Five per cent variation in weight or $\frac{1}{4}$ in. variation in any dimension from the refiner's published list or purchaser's specified size shall be considered good delivery; provided, however, that wire bars may vary in length 1 per cent from the listed or specified length, and cakes 3 per cent from the listed or specified size in any dimension greater than 8 in. The weight of ingot and ingot-bar copper shall not exceed that specified by more than 10 per cent, but otherwise its variation is not important.

Claims.

8. Claims shall be made in writing within thirty days of receipt of copper at the customer's mill, and the results of the customer's tests shall accompany such claims. The refiner shall be given one week from date of receipt of complaint to investigate his records, and shall then either agree to replace the defective copper or send a representative to the mill. No claims will be considered unless made as above stated, and if the copper in question, unused, cannot be shown to the refiner's representative.

Claims against quality will be considered as follows:

(*a*) Resistivity by furnace charges, ingot lots, or ingot-bar lots.

(*b*) Metal contents by furnace charges, ingot lots, or ingot-bar lots.

(*c*) Physical defects by individual pieces.

(*d*) Variation in weights or dimensions by individual pieces.

Investigation of Claims.

9. The refiner's representative shall inspect all pieces where physical defects or variation in weight or dimension are claimed. If agreement is not reached, the question of fact shall be submitted to a mutually agreeable umpire, whose decision shall be final.

In a question of metal contents each party shall select a sample of two pieces. These shall be drilled in the presence of both parties, several holes approximately $\frac{1}{2}$ in. in diameter being drilled completely through each piece; scale from set shall be rejected. No lubricant shall be used and drilling shall not be forced sufficiently to cause oxidation of chips. The resulting samples shall be cut up, mixed, and separated into three parts, each of which shall be placed in a sealed package, one for each party and one for the umpire if necessary. Each party shall make an analysis, and if the results do not establish or dismiss the claim to the satisfaction of both parties the third sample shall be submitted to a mutually agreeable umpire, who shall determine the question of fact, and whose determination shall be final.

In a question of resistivity each party shall select two samples, and in the presence of both parties these shall be rolled hot and drawn cold into wire of 0.080 in. diameter, approximately, which shall be annealed at approximately 500° C. Three samples shall be cut from each coil and the same procedure followed as described in the previous paragraph.

Settlement of Claims.

10. The expenses of the shipper's representative and of the umpire shall be paid by the loser, or divided in proportion to the concession made in case of compromise. In case of rejection being established, the damage shall be limited to payment of freight both ways by the refiner for substitution of an equivalent weight of copper meeting these specifications.

EXPLANATORY NOTE.

These specifications have been drawn to cover the peculiar trade situation which has classified the large production of copper from this geographical district as a product in a class by itself.

It is realized that a better classification from an academic point of view could be made by method of production or by chemical composition, but the trade does not yet seem ready for such a step.

AMERICAN SOCIETY FOR TESTING MATERIALS

PHILADELPHIA, PA., U. S. A.

AFFILIATED WITH THE

INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

STANDARD SPECIFICATIONS

FOR

ELECTROLYTIC COPPER WIRE BARS, CAKES, SLABS, BILLETS, INGOTS, AND INGOT BARS.

ADOPTED AUGUST 25, 1913.

Marks. 1. All wire bars, cakes, slabs, and billets shall be stamped with the maker's brand and furnace charge mark. Ingots and ingot bars shall have a brand stamped or cast in, but need have no furnace charge mark.

Lots. 2. The refiner shall arrange carloads or lots so that as far as possible each shall contain pieces from but one furnace charge, in order to facilitate testing by the user.

Quality. 3. (*a*) *Metal Content.*—The copper in all shapes shall have a purity of at least 99.880 per cent, as determined by electrolytic assay, silver being counted as copper.

(*b*) *Resistivity.*—All wire bars shall have a resistivity not to exceed 0.15535 international ohms per meter-gram at 20° C. (annealed); all ingot and ingot bars shall have a resistivity not to exceed 0.15694 international ohms per meter-gram at 20° C. (annealed).

Cakes, slabs, and billets shall come under the ingot classification, except when specified for electrical use at time of purchase, in which case wire-bar classification shall apply.

Physical Standard.

4. Wire bars, cakes, slabs, and billets shall be substantially free from shrink holes, cold sets, pits, sloppy edges, concave tops, and similar defects in set or casting. This clause shall not apply to ingots or ingot bars, in which case physical defects are of no consequence.

Weight of Individual Pieces.

5. Five per cent variation in weight or $\frac{1}{4}$ in. variation in any dimension from the refiner's published list or purchaser's specified size shall be considered good delivery; provided, however, that wire bars may vary in length 1 per cent from the listed or specified length, and cakes 3 per cent from the listed or specified size in any dimension greater than 8 in. The weight of ingot and ingot-bar copper shall not exceed that specified by more than 10 per cent, but otherwise its variation is not important.

Claims.

6. Claims shall be made in writing within thirty days of receipt of copper at the customer's mill, and the results of the customer's tests shall accompany such claims. The refiner shall be given one week from date of receipt of complaint to investigate his records, and shall then either agree to replace the defective copper or send a representative to the mill. No claims shall be considered unless made as above stated, and if the copper in question, unused, cannot be shown to the refiner's representative.

Claims against quality will be considered as follows:

(*a*) Resistivity by furnace charges, ingot lots, or ingot-bar lots.

(*b*) Metal contents by furnace charges, ingot lots, or ingot-bar lots.

(*c*) Physical defects by individual pieces.

(*d*) Variation in weights or dimensions by individual pieces.

Investigation of Claims.

7. The refiner's representative shall inspect all pieces where physical defects or variation in weight or dimension are claimed. If agreement is not reached, the question of fact shall be submitted to a mutually agreeable umpire, whose decision shall be final.

In a question of metal contents each party shall select a sample of two pieces. These shall be drilled in the presence of both parties, several holes approximately $\frac{1}{2}$ in. in diameter

being drilled completely through each piece; scale from set shall be rejected. No lubricant shall be used and drilling shall not be forced sufficiently to cause oxidation of chips. The resulting samples shall be cut up, mixed, and separated into three parts, each of which shall be placed in a sealed package, one for each party and one for the umpire if necessary. Each party shall make an analysis, and if the results do not establish or dismiss the claim to the satisfaction of both parties the third sample shall be submitted to a mutually agreeable umpire, who shall determine the question of fact, and whose determination shall be final.

In a question of resistivity each party shall select two samples, and in the presence of both parties these shall be rolled hot and drawn cold into wire of 0.080 in. diameter, approximately, which shall be annealed at approximately 500° C. Three samples shall be cut from each coil and the same procedure followed as described in the previous paragraph.

Settlement of Claims.

8 The expenses of the shipper's representative and of the umpire shall be paid by the loser, or divided in proportion to the concession made in case of compromise. In case of rejection being established, the damage shall be limited to payment of freight both ways by the refiner for substitution of an equivalent weight of copper meeting these specifications.

REPORT OF COMMITTEE C-1

ON

STANDARD SPECIFICATIONS FOR CEMENT.

The committee begs to report that in compliance with the invitation authorized in the following resolution:

> "In order to secure uniformity in specifications for cement, it is recommended that the Board of Direction of the American Society of Civil Engineers, The Committee on Standard Specifications for Cement of the American Society for Testing Materials, and the Government Departmental Committee on the Specifications for Cement, be each requested to appoint a committee of three to confer for the purpose of reconciling differences.",

which it presented in its last report, the Board of Direction of the American Society of Civil Engineers appointed Messrs. Alfred Noble, George S. Webster, and Richard L. Humphrey; the United States Government Departmental Committee on Specifications for Cement appointed Messrs. Arthur P. Davis, Asa E. Philips, and Rudolph J. Wig; and your committee appointed Messrs. George F. Swain, Olaf Hoff, and Clifford Richardson.

These three committees met on October 26, 1912, and organized under the title of Joint Conference on Uniform Methods of Tests and Standard Specifications for Cement, with the following officers:

Chairman,	Alfred Noble.
Vice-Chairman	Arthur P. Davis.
Secretary	Richard L. Humphrey.
Executive Committee	Rudolph J. Wig.
	Richard L. Humphrey.

A number of meetings of this Conference have been held, at which have been formulated plans for conducting various

tests and such other investigations as were deemed necessary in order to secure data upon which to base an agreement. This work has not progressed sufficiently to admit of conclusions; but it is expected that the Conference will reach an agreement during the present year, which will be reported to the several Societies represented in the Conference. The committee feels that the creation of this Conference is the most important step that has been taken towards the development of Uniform Methods of Tests and Standard Specifications for Cement and it is hoped that an agreement will be reached, by which a single standard will be adopted for this country. Pending a final report from this Conference your committee has taken no action.

At all meetings of the Joint Conference there has been a full attendance of the representatives of your committee.

Respectfully submitted on behalf of the committee,

GEORGE F. SWAIN,
Chairman.

RICHARD L. HUMPHREY,
Secretary.

REPORT OF COMMITTEE C-2

ON

REINFORCED CONCRETE.

The committee has continued its affiliations with the Joint Committee on Concrete and Reinforced Concrete, consisting of special committees appointed by the American Society of Civil Engineers, American Society for Testing Materials, American Railway Engineering Association and the Association of American Portland Cement Manufacturers, and a majority of the members have attended all meetings of the Joint Committee.

The committee has during the year revised its first progress report; has considered various papers and discussions relating to this report; differences between the members of the committee have been discussed and the report finally reviewed at a meeting held November 20, 1912, at which the report herewith submitted in the accompanying Appendix was adopted. The report was presented and accepted at the annual meeting of the American Society of Civil Engineers on January 15, 1913, and was also presented and accepted at the annual meeting of the American Railway Engineering Association on March 20, 1913.

The several committees composing the Joint Committee have been continued with the view of making any further modifications in this report which may be found desirable. The committee recommends that the report herewith submitted be accepted and printed in the Proceedings, and that the committee be continued.

Respectfully submitted on behalf of the committee,

F. E. TURNEAURE,
Chairman.

RICHARD L. HUMPHREY,
Secretary.

APPENDIX.

REPORT ON CONCRETE AND REINFORCED CONCRETE.

REVISED AT THE MEETING OF THE JOINT COMMITTEE ON CONCRETE AND REINFORCED CONCRETE, NEW YORK, N. Y., NOVEMBER 20, 1912.

DECEMBER 1, 1912.

I. INTRODUCTION.

1. APPOINTMENT AND WORK OF COMMITTEE.

In 1903 and 1904 special committees were appointed by the American Society of Civil Engineers, American Society for Testing Materials, American Railway Engineering and Maintenance of Way Association and the Association of American Portland Cement Manufacturers, for the purpose of investigating current practice and providing definite information concerning the properties of concrete and reinforced concrete and to recommend necessary factors and formulas required in the design of structures in which these materials are used. The history of the appointment of the committees is as follows:

At the annual convention of the American Society of Civil Engineers held at Asheville, N. C., June 11, 1903, the following resolution was adopted:

> It is the sense of this meeting that a special committee be appointed to take up the question of concrete and steel concrete, and that such committee cooperate with the American Society for Testing Materials and the American Railway Engineering and Maintenance of Way Association.

Following the adoption of this resolution, a Special Committee on Concrete and Steel Concrete was appointed by the Board of Direction on May 31, 1904. At the Annual Meeting, held January 18, 1905, the title of this special committee was, at

the request of the Committee, changed to "Special Committee on Concrete and Reinforced Concrete." This Special Committee held its first meeting at Atlantic City, N. J., June 17, 1904, and effected an organization; Mr. C. C. Schneider was appointed Chairman and Mr. J. W. Schaub, Secretary. Mr. Schneider resigned from the Committee on January 3, 1911, and the Board of Direction on January 31, 1911, appointed Mr. J. R. Worcester as Chairman. On the resignation of Mr. J. W. Schaub, Mr. Richard L. Humphrey was appointed Secretary on October 11, 1905.

At the first meeting of the Committee it was decided to cooperate with similar committees which had been appointed by the American Society for Testing Materials and the American Railway Engineering and Maintenance of Way Association through the organization of a Joint Committee on Concrete and Reinforced Concrete.

At the annual meeting of the American Society for Testing Materials held July 1, 1903, at the Delaware Water Gap, the following resolution was unanimously adopted:

> That the Executive Committee be requested to consider the desirability of appointing a committee on "Reinforced Concrete," with a view of cooperating with the committees of other societies in the study of the subject.

At the meeting of the Executive Committee of the American Society for Testing Materials, held December 5, 1903, a special committee on "Reinforced Concrete" was appointed.

The American Railway Engineering and Maintenance of Way Association appointed a Committee on Masonry on July 20, 1899, with instructions as a part of its duties to prepare specifications for concrete masonry. A preliminary set of specifications for Portland cement concrete was reported to and adopted by the Association on March 19, 1903. At the meeting held in Chicago on March 17, 1904, the Committee on Masonry was authorized to cooperate with the Special Committee on Concrete and Reinforced Concrete of the American Society of Civil Engineers, and following this action a special sub-committee was appointed.

At a meeting of the several special committees representing the above mentioned societies, held at Atlantic City, N. J., June 17, 1904, arrangements were completed for collaborating the

work of these several committees through the formation of the Joint Committee on Concrete and Reinforced Concrete. Mr. C. C. Schneider was elected temporary chairman and Prof. A. N. Talbot, temporary secretary. The proposed plan of action of the special committee of the American Society of Civil Engineers was outlined, involving the appointment of sub-committees on Plan and Scope, on Tests, and on Ways and Means.

The Joint Committee, at its first meeting, invited the Association of American Portland Cement Manufacturers to join in its deliberations through a committee appointed for the purpose.

The Joint Committee at meetings at St. Louis in October, 1904, and at New York in the following January perfected its organization by the adoption of rules and the choice of Mr. C. C. Schneider as Chairman, Mr. Emil Swensson, Vice-Chairman, and Mr. J. W. Schaub, Secretary. Later, on the resignation of Mr. Schaub, Mr. Richard L. Humphrey was chosen Secretary. Sub-Committees on Plan and Scope, on Tests, and on Ways and Means, were appointed.

The Joint Committee as thus organized, consisted of the following members:

OFFICERS.

Chairman—C. C. SCHNEIDER.
Vice-Chairman—EMIL SWENSSON.
Secretary—RICHARD L. HUMPHREY.

MEMBERS.

American Society of Civil Engineers (Special Committee on Concrete and Reinforced Concrete):

Greiner, J. E., Consulting Engineer, Baltimore and Ohio Railroad, Baltimore, Md.

Hatt, W. K., Professor of Civil Engineering, Purdue University, Lafayette, Ind.

Hoff, Olaf, Vice-President, Butler Brothers, Hoff and Company, New York, N. Y.

Humphrey, Richard L., Consulting Engineer; Engineer in Charge, Structural Materials Testing Laboratories, U. S. Geological Survey, Philadelphia, Pa.

Lesley, R. W., President, American Cement Company, Philadelphia, Pa.

Schaub, J. W., Consulting Engineer, Chicago, Ill.

Schneider, C. C., Consulting Engineer, Philadelphia, Pa.
Swensson, Emil, Consulting Engineer, Pittsburgh, Pa.
Talbot, A. N., Professor of Municipal and Sanitary Engineering, in charge of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.
Worcester, J. R., Consulting Engineer, Boston, Mass.

American Society for Testing Materials (Committee on Reinforced Concrete):
Fuller, William B., Consulting Engineer, New York, N. Y.
Heidenreich, E. Lee, Consulting Engineer, New York, N. Y.
Humphrey, Richard L., Consulting Engineer; Engineer in Charge, Structural Materials Testing Laboratories, U. S. Geological Survey, Philadelphia, Pa.
Johnson, Albert L., Consulting Engineer, St. Louis, Mo.
Lanza, Gaetano, Professor of Theoretical and Applied Mechanics, Massachusetts Institute of Technology, Boston, Mass.
Lesley, R. W., President, American Cement Company, Philadelphia, Pa.
Marburg, Edgar, Professor of Civil Engineering, University of Pennsylvania, Philadelphia, Pa.
Mills, Charles M., Principal Assistant Engineer, Philadelphia Rapid Transit Company, Philadelphia, Pa.
Moisseiff, Leon S., Engineer of Design, Department of Bridges, New York, N. Y.
Quimby, Henry H., Assistant, Engineer of Bridges, Bureau of Surveys, Philadelphia, Pa.
Taylor, W. P., Engineer in Charge of Testing Laboratory, Philadelphia, Pa.
Thompson, Sanford E., Consulting Engineer, Newton Highlands, Mass.
Turneaure, F. E., Dean of College of Mechanics and Engineering, University of Wisconsin, Madison, Wis.
Wagner, Samuel Tobias, Assistant Engineer, Philadelphia and Reading Railroad, Philadelphia, Pa.
Webster, George S., Chief Engineer, Bureau of Surveys, Philadelphia, Pa.

American Railway Engineering Association (Sub-Committee on Reinforced Concrete):
Beckwith, Frank, Engineer of Bridges and Structures, Lake Shore and Michigan Southern Railroad, Cleveland, Ohio.
Boynton, C. W., Inspecting Engineer, Cement Department, Illinois Steel Company, Chicago, Ill.
Cunningham, A. O., Chief Engineer, Wabash Railroad, St. Louis, Mo.
Scribner, Gilbert H., Jr., Contracting Engineer, Chicago, Ill.
Swain, George F., Professor of Civil Engineering, Massachusetts Institute of Technology, Boston, Mass.

Association of American Portland Cement Manufacturers (Committee on Concrete and Steel Concrete):

Fraser, Norman D., President, Chicago Portland Cement Company, Chicago, Ill.

Griffiths, R. E., Vice-President, American Cement Company, Philadelphia, Pa.

Hagar, Edward M., Manager, Cement Department, Illinois Steel Company, Chicago, Ill.

Newberry, Spencer B., Manager, Sandusky Portland Cement Company, Sandusky, Ohio.

Since organization the following changes have occurred in the personnel of the Joint Committee:

J. W. Schaub, died March 30, 1909.
C. C. Schneider, resigned January 3, 1911.
Ernest R. Ackerman, resigned.
T. J. Brady, resigned.
Frank Beckwith, resigned.
A. O. Cunningham, resigned.
George F. Swain, resigned.

The following representatives of the American Railway Engineering Association have since been appointed:

Thompson, F. L., Engineer of Bridges and Buildings, Illinois Central Railroad, Chicago, Ill.

Alternates:

Hotchkiss, L. J., Assistant Bridge Engineer, Chicago, Burlington and Quincy Railroad, Chicago, Ill.

Prior, J. H., Assistant Engineer, Chicago, Milwaukee and St. Paul Railway, Chicago, Ill.

Schall, F. E., Bridge Engineer, Lehigh Valley Railroad, South Bethlehem, Pa.

Tuthill, Job, Assistant Engineer, Cincinnati, Hamilton and Dayton Railway, Cincinnati, Ohio.

At a meeting of the Joint Committee held at Atlantic City, N. J., June 30, 1911, Mr. J. R. Worcester was elected chairman.

Meetings of the Joint Committee have been held as follows:

June 17, 1904, at Atlantic City, N. J.
Oct. 4, 5, 6, 1904, at St. Louis, Mo.
Jan. 17, 1905, at New York, N. Y.
June 21, 1905, at Cleveland, Ohio.
June 30, 1905, at Atlantic City, N. J.
Oct. 11, 1905, at New York, N. Y.

Dec. 14, 1905, at New York, N. Y.
June 21, 1906, at Atlantic City, N. J.
Dec. 13, 1906, at New York, N. Y.
Jan. 15, 1907, at New York, N. Y.
March 7, 1907, at New York, N. Y.
March 18, 1907 at Chicago, Ill.
June 21, 22, 1907, at Atlantic City, N. J.
Dec. 10, 1907, at New York, N. Y.
Oct. 27, 28, 1908, at New York, N. Y.
Dec. 9, 10, 11, 1908, at Philadelphia, Pa.
June 30, 1911, at Atlantic City, N. J.
Nov. 20, 1912, at New York, N. Y.

At the meeting of the Joint Committee at St. Louis in October, 1904, it was determined to arrange tests at such technological institutions as were provided with the requisite facilities and were willing to cooperate, the Committee, through its Sub-Committee on Ways and Means, to provide materials, and through its Sub-Committee on Tests, to consult as to lines of testing and to advise as to methods. The following ten institutions, Case School of Applied Science, Columbia University, Cornell University, University of Illinois, State University of Iowa, Massachusetts Institute of Technology, University of Minnesota, Ohio State University, Purdue University and University of Wisconsin, undertook a preliminary series of tests and carried them through, in due time reporting their results to the Committee.

Through the inability of the Committee to do as much as it had hoped by way of furnishing uniform materials for these tests and exercising a proper supervision, the results were not as serviceable to the Committee as they would have been if the full plans had been carefully carried out; but much important information was received in this manner, and the Committee desires to express its gratitude to the professors and students who so kindly assisted in this work.

The results were collated and edited by the Secretary of the Committee at the Structural Materials Testing Laboratories of the U. S. Geological Survey, St. Louis, and the results in typewritten form were circulated among the members of the Committee. It was hoped that they might be published by the Geological Survey as a Bulletin, but in that the Committee was disappointed, though some of the results have been published in bulletins and papers issued by their authors.

In June, 1905, the U. S. Geological Survey proposed to cooperate with the Joint Committee to the extent of placing the tests made at the St. Louis Laboratory at the service of the Committee and allowing the Committee the privilege of advising as to what tests of concrete and reinforced concrete should be conducted there. This cooperation was welcomed by the Committee and was brought about by the fact that the Secretary of the Committee, who was also the chairman of the sub-committee on tests, was in charge of the St. Louis Laboratory.

During the five years in which the investigations of structural materials were in progress under the direction of the U. S. Geological Survey, a large amount of data relating to concrete and reinforced concrete was obtained. These investigations have included the survey of the constituent materials of concrete such as sands, gravels and crushed stone, in the various parts of the United States, covering their strength as mortars or concretes in various consistencies and proportions.

A number of series of tests of plain and reinforced concrete beams were made, covering the influence of character of aggregates, proportions and age, percentage of reinforcement, the effect of the variation in span relative to the depth, methods of anchorage of the reinforcement, etc., upon strength. A study was made of the effect of the personal equation in tests of beams, made by three construction companies operating in St. Louis and by the employees of the testing laboratory. Tests covering bond, shear, compressive strength, and weight per cubic foot, for various classes of aggregates, were made.

Among other investigations were tests of reinforced concrete slabs, 12 ft. span supported at two and four edges, of strength and other properties of cement hollow building blocks, of the permeability of cement mortars and concretes, value of various waterproofing and dampproofing preparations, effect of alkali and sea water on cement mortars and concretes, the fire-resistive properties of concrete and other structural materials, and these have been made and published, in part.

The collation and study of the data obtained were seriously handicapped through lack of funds available for this purpose, the large part of the appropriation being devoted to work urgently required by the various Government Bureaus. Of the

annual Government appropriation of $100,000 there was never available more than $15,000 per annum for investigation of concrete and reinforced concrete, and several years the amount did not exceed $5,000 a year. None of this was available for the publication of results, and the allotment from the funds provided for all Government printing was wholly inadequate for the purpose.

On June 30, 1910, Congress transferred this work to the Bureau of Standards together with the data collected. It is understood that arrangements have been made by which the data of the tests will be published as rapidly as conditions permit.

The Committee has had the benefit of the results of investigations by a number of laboratories some of which were under the direct supervision of its members. The extent and varied character of the tests, and their interpretation by those in charge, made them of especial value to the Committee.

The Committee also has had the advantage of investigations made in foreign laboratories.

At a meeting of the Joint Committee at Atlantic City, June 30, 1905, it was decided to divide among its members the work of collating and digesting the results of all available tests on concrete and reinforced concrete, and in pursuance of this resolution, sub-committees were appointed on the following subjects:

Historical.
Aggregates, Proportions and Mixing.
Physical Characteristics, Waterproofing, etc.
Strength and Elastic Properties.
Simple Reinforced Concrete Beams.
T-Beams, Floor Slabs, etc.
Columns and Piles.
Fire-resistive Qualities.
Failures of Concrete Structures.
Arches.

A large amount of work was done by these sub-committees and extensive reports were submitted by most of them. These reports were typewritten in manifold and circulated among the members of the Joint Committee, and were of great value to the Committee in arriving at its conclusions.

The Sub-Committee on Ways and Means raised by subscription about $8,000 which was used for preliminary investigations and expenses incident to printing its report and carrying on work of the Committee. The Committee desires to express its appreciation for contributions and for donations of materials.

Even with this support the field of activity of the Committee has been limited in scope and it has been unable to undertake investigations of its own.

In 1908 the Committee began the preparation of the Progress Report which was submitted to the Society in January, 1909. A preliminary outline was prepared by the Secretary and submitted to the Committee in October. On October 27, a meeting of the Joint Committee was held at New York, at which the report was discussed paragraph by paragraph and chapters were referred to sub-committees and carefully revised during the following three weeks. The whole, as thus amended and revised, was again submitted in print to a full meeting held in Philadelphia, December 9, 10 and 11, and again was gone over in great detail. As a result of those two meetings, a considerable amount of matter which it was at first intended to include was omitted on account of slight disagreements as to its form, and lack of time to work it into satisfactory shape, and to this fact may be attributed some of the criticisms which have been elicited. It is hoped, in this report, to avoid these objections.

In the spring of 1911 the work of revising the 1909 progress report was taken up and a number of meetings were held. The discussions submitted to the American Society of Civil Engineers and subsequent papers relating to the same subject were carefully considered, and differences of opinion between members of the Committee were threshed out.

Through the cooperation of the societies represented on the Joint Committee the report was again put in type and the necessary editions were printed for the use of the members of the Committee, the last bearing the date of August 1, 1911. In the form thus reached the report remained until November 20, 1912, when the Committee again met in New York and gave a final review needed to bring it into the shape in which it is now presented.

2. HISTORICAL SKETCH OF USE OF CONCRETE AND REINFORCED CONCRETE.

In considering the history of concrete and reinforced concrete, a distinction should be made between the two. The use of concrete extends back to long before the Christian era—while on the other hand the art of reinforced concrete is in its infancy.

The use of concrete by the ancient Romans was due to the discovery of the fact that volcanic ash or puzzolan, when mixed with slaked lime, made a cement possessing hydraulic properties. The durability of this work of the Romans was due largely to favorable climatic conditions and the character of the cement used.

From the downfall of the Roman Empire to the last half of the eighteenth century the manufacture of cement seems to have been discontinued. The Roman cement mortars and concretes surviving the ravages of the elements became so hard that the cement acquired a reputation that led the early experimenters of the eighteenth century to seek to recover this supposed lost Roman art. Evidently no concrete was used during this period, for the necessity of simultaneous induration in the interior and exterior of the mass prevents the use of lime alone in concrete and requires the use of some material having hydraulic qualities. This fact limited the use of concrete to regions where hydraulic limes and cements were to be found.

In 1756 Smeaton discovered that an argillaceous limestone produced a lime that would set and harden under water, but no immediate appreciation of this knowledge appears to have resulted.

Natural cement was first manufactured by Parker in 1795 as a result of an attempt to equal or excel Roman cement, and in 1796 he took out an English patent. Natural cement was first produced in America in 1818 and for a long time was the principal cement used. With the introduction of Portland cement, and the reduction in the cost of manufacture, there has been a gradual substitution of Portland for natural cement. The production of natural cement reached a maximum of nearly 10,000,000 barrels in 1899 and has since gradually decreased to about 900,000 barrels in 1911.

The art of manufacturing Portland cement was discovered in 1811 by Joseph Aspdin and patented by him in 1824. He

called this cement "Portland" by reason of its resemblance to a building stone obtained from the Isle of Portland, off the coast of England. Up to 1850 very little progress was made in the manufacture of this cement in England. Since 1855, however, the increase in the production in Europe has been steady, and its superiority has led to a gradually increasing use in such structures as require concrete in mass, as foundations, fortifications, seawalls, docks, locks, etc. While Portland cement was first manufactured in 1824 and was produced in 1871 by David O. Saylor at Coplay, Pa., and by Thomas Millen at South Bend, Ind., it was not until the early eighties that it was manufactured to any extent in America. From that time on the production has rapidly increased, reaching the enormous total of nearly 80,000,000 barrels in 1911. This increase in production has been largely stimulated by the reduction in cost of Portland cement through the perfection of the American methods, the introduction of reinforced concrete and the extensive use of cement during the last few years.

In 1850 Joseph Gibbs obtained a British patent for casting solid walls in wooden molds, and in 1897 C. W. Stevens obtained a patent for making artificial cast stone with concrete. It is not clear, however, that these inventors were the first to use the material in a similar way.

The origin of the idea of increasing the load-carrying capacity of concrete by reinforcing it with metal embedded in it is generally attributed to Joseph Monier, a French gardener, who used a wire frame or skeleton embedded in concrete in the construction of flower pots, tubs and tanks in 1867, and for which he obtained the first patent of the kind in the same year. This was not the first use of the material, however, as Lambot constructed a boat of reinforced concrete in 1850 which was exhibited at the Paris Exposition in 1853. He took out an English patent in 1855.

In France in 1861, Francois Coignet applied the principles of reinforced concrete in the construction of beams, arches, pipes, etc., and with Monier exhibited some of their work at the Paris Exposition in 1867. Coignet also took out an English patent in 1855. In England in 1854, W. B. Wilkinson took out a patent for a reinforced concrete floor. In America, Ernest L. Ransome

used metal in combination with concrete as early as 1874, and W. E. Ward erected, in 1875, at Port Chester, New York, a house built entirely of reinforced concrete.

Monier, while not the first to apply it, obtained the first patents for reinforced concrete, the German and American rights of which he disposed of to G. A. Wayss and Company in 1880. Wayss and J. Bauschinger shortly after began the tests on this material which were published in 1887.

Thaddeus Hyatt, an American engineer, employed David Kirkaldy of London to make the experiments on reinforced concrete which Hyatt published in 1877. The theories of Hyatt were applied in a practical way to building construction in 1877 by H. P. Jackson of San Francisco.

In America, Ransome, between 1874 and 1884, constantly increased his application of metal reinforcement consisting of old wire rope and hoop iron, gradually realizing the necessity for using it with a greater regard for its proper position in the mass, and in 1884 took out the first patent for a deformed bar. Prior to this reinforced concrete was used but little in the United States. Ransome built his first important structure in 1890, the Leland Stanford Jr. Museum Building, 312 ft. long, two stories high with basement, the walls and floors of which were of reinforced concrete. Since 1891, when the first slabs of reinforced concrete were used in America, the development has been rapid.

The introduction of this form of construction proceeded more slowly in Europe and between 1891 and 1894 Moeller in Germany, Wünsch and Emperger in Hungary, Melan in Austria and Hennebique in France were pioneers in its development. Hennebique built reinforced concrete slabs as early as 1879 but did not patent his system of construction until 1892.

The first published method of computation was by Koenen and Wayss in 1886. Subsequent theories have been advanced by de Mazas, Neuman, Melan, Coignet, de Tedesco, Von Thullie, Ostenfeld, Sanders, Spitzer, Lutken, Ritter, Hatt, Talbot, Turneaure and others. As early as 1884 Ransome worked out methods of calculation independent of other investigators, and in 1899 Considére published his important series of tests from which he deduced his methods of calculation.

During the last ten years the earlier theories have been somewhat modified as experience has been gained, and as the fund of experimental knowledge has accumulated. The trend of the modifications has been towards greater harmony in methods of calculation. Some of the earlier assumptions have been proved fallacious and generally abandoned. On the other hand, some of the refinements of calculation, though known to be in accordance with facts, have, by general consent, been discarded, as they do not affect the design materially or are taken into account by a modification of the constants. Among these are the value of the concrete in the tension side of a beam, and the lack of a uniform modulus of elasticity in compression of concrete under widely varying stress. The earlier theories did not deal with the diagonal tension under shearing stresses. This has been found to be a most important consideration and much attention has been paid to it in recent years. In spite of the study which has already been given it, however, there is still much to learn in this direction. The action of various forms of reinforcement in columns has received much consideration, and there is still a wide difference of opinion as to the efficacy of some forms of column reinforcement. Many experiments have been made in this branch of the subject, and practice appears to be gradually converging towards greater uniformity.

In the preparation of this historical sketch the Committee has endeavored to verify the facts and has received the cooperation of H. Kempton Dyson, Secretary of the Concrete Institute of England, Alfred Huser, President Deutscher Beton-Verein, C. von Bach, Otto Leube, of Germany, Karl Naehr, of Austria, Joseph Schustler, of Hungary, and H. I. Hannover, of Denmark, to whom the Committee wishes to acknowledge its appreciation and thanks.

3. AUTHORITIES ON WHICH RECOMMENDATIONS ARE BASED.

It has been suggested that a report such as this should include all the data upon which conclusions are based. The impracticability of this may not be realized by those who are not familiar with the enormous quantity of matter involved. There are, however, reasons other than the magnitude of the task which tend to show that full publication is not advisable. One of

these is that most of the experimental results have already appeared in print and are now available, and a reprint of them would be of no great advantage to anyone. Where originally printed they are frequently accompanied with comments and deductions by their author, which are of great value as such but could scarcely be copied by the Committee. Another reason against publication is that in the large part of the experimental work consulted it has been found that certain vitally important information, either with regard to the materials, the way in which they are manipulated or as to the precise results reached, are lacking. The omission of measurements of deformations, of course, frequently renders results of little value. While such tests may have some use on account of particular facts developed, a large part may be useless, and consequently unsuitable for publication. The difficulty of separating the valuable from the valueless would be almost insurmountable.

It may not be improper, however, to append the following list of authors and references, as comprising a considerable part of the most important published material upon the subject under consideration:

C. v. BACH.—*Compressive Tests:* Deutsche Bauzeitung, 1905, 68 (No. 17). Mitteilungen über Forschungsarbeiten, Nos. 22, 29, 39, 45–47, 72–74.

E. CANDLOT.—*Cements and Mortars:* Ciments et Chaux Hydrauliques, 1898, p. 446, 447.

HOWARD A. CARSON.—*Plain and Reinforced Concrete Beams:* Boston Transit Commission, 10th Annual Report, 1904, Appendix G.

A. CONSIDÉRE.—*Reinforced Beams and Columns:* Comptes Rendus de l'Academie des Sciences, CXXVII, p. 992; CXXIX, p. 467; CXXXV, 8 Sept., 1902; CXL, 30 June, 1905.

F. v. EMPERGER.—*Forschungsarbeiten auf dem Gebiete des Eisenbetons.* No. 8.

R. FERET.—*Sur la compacité des mortiers hydrauliques;* Annales des Ponts et Chaussées, 1892, II. *Composition, Various Tests of Reinforcing:* Etude Experimentale du ciment armé, 1906.

WILLIAM B. FULLER and SANFORD E. THOMPSON.—*Composition and Density:* Transactions American Society of Civil Engineers, Vol. LIX, 1907, p. 67.

WILLIAM K. HATT.—*Reinforced Concrete Beams:* Proceedings American Society for Testing Materials, Vol. II, 1902, p. 161; Journal Western Society of Engineers, June, 1904.

JAMES E. HOWARD.—*Watertown Arsenal Tests of Cubes and Reinforced Columns:* Tests of Metals, U. S. A., 1897, 1898, 1899, 1903, 1905, and 1906; Proceedings American Society for Testing Materials, Vol. VI, 1906, p. 346.

RICHARD L. HUMPHREY.—*St. Louis Laboratory Tests of Aggregates, Beams, Prisms, Fire Resistance:* U. S. Geological Survey, Bulletins 324, 329, 331, 344, 370, and Bureau of Standards, Technologic Paper 2.

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In addition to the authorities above quoted, the Committee desires to acknowledge with thanks the discussions of its progress report which have appeared from time to time and to say that all the points brought out therein have been carefully weighed.

4. CHARACTER OF REPORT PRESENTED.

At the time of the appointment of the Committee, in 1904, there existed a great diversity of opinion in America as to methods of design, safe allowable working stresses and methods of proportioning, handling, etc. A great deal of experimental

work had been done, but there was need of a clearing house through which results could be compared and divergent views harmonized. During the interval between the appointment of the Committee and the preparation of its first progress report, rapid advance was made in the art of concrete construction aided by the results of the investigations and the experience acquired by constructors. This report, which was submitted in 1909, attempted to embody recommendations for safe methods of construction and design in accordance with the best practice of the day. It would have been impossible for such a report to meet with the approval of all, and the Committee is well satisfied that its most vital recommendations have met with quite general acceptance by the engineers of the country.

Since the appearance of the first progress report many experiments have been conducted by some of the technical institutions and by private and corporate interests, and through these and through longer experience in construction by its members and others, the Committee is now able to make some perfecting modifications of its former report and to add some entirely new material. The time therefore seems opportune for presenting this second report bringing the work up to date.

The Committee would point out that while the report deals with every kind of stress to which concrete is subjected and includes all ordinary conditions of proportioning and handling, it does not go into all types of construction or all the applications to which concrete and reinforced concrete may be put.

It is not to be assumed that the Committee in presenting this report wishes to imply that further improvements are not possible. A careful reading will disclose many points on which the present deductions are regarded as only tentative, but it has been the aim of the Committee to cover as fully as possible recommendations based on the present state of the art.

This report is what the word implies and nothing more; it is not a "specification," but may be used as a basis for specifications.

The use of concrete and reinforced concrete involves the exercise of good judgment to a greater degree than for any other building material.

Rules can not produce or supersede judgment; on the con-

trary, judgment should control the interpretation and application of rules.

II. ADAPTABILITY OF CONCRETE AND REINFORCED CONCRETE.

The adaptability of concrete and reinforced concrete for engineering structures, or parts thereof, is now so well established that they may be considered the recognized materials of construction. They have proved satisfactory materials, when properly used, for those purposes for which their qualities make them particularly suitable.

1. USES.

Concrete is a material of very low tensile strength and capable of sustaining but very small tensile deformations without rupture; its value as a structural material depends chiefly upon its durability, its fire-resistive qualities, its strength in compression, its relatively low cost, and its adaptability to placing, especially where space is cramped or limited. Its strength increases generally with age.

Concrete is well adapted for structures in which the principal stresses are compressive, such as foundations, dams, retaining and other walls, tunnels, piers, abutments, short columns and, in many cases, arches. In the design of massive concrete, the tensile strength of the material in resisting principal stresses must generally be neglected.

By the use of metal reinforcement to resist the principal tensile stresses, concrete becomes available for general use in a great variety of structures and structural forms. This combination of concrete and metal is particularly advantageous in the beam, where both compression and tension exist; it is also advantageous in the column where the main stresses are compressive, but where cross-bending may exist. In structures resisting lateral forces it possesses advantages over plain concrete in that it may be designed so as to utilize more fully the strength rather than the weight of the material. Metal reinforcement may also be of value in distributing cracks due to shrinkage and temperature changes.

2. PRECAUTIONS.

Failures of reinforced concrete structures are usually due to any one or a combination of the following causes: defective design, poor material, faulty execution, and premature removal of forms.

The defects in a design may be many and various. The computations and assumptions on which they were based may be faulty and contrary to the established principles of statistics and mechanics; the unit stresses used may be excessive, or the details of the design defective.

Articulated concrete structures designed in imitation of steel trusses may be mentioned as illustrating a questionable use of reinforced concrete, and such structures are not recommended.

Poor material is sometimes used for the concrete, as well as for the reinforcement. The use of poor aggregates, especially sand, which have not been tested is a common source of defect. Inferior concrete is frequently due also to lack of experience on the part of the contractor and his superintendents, or to the absence of proper supervision.

An unsuitable quality of metal for reinforcement is sometimes prescribed in specifications, for the purpose of reducing the cost. For steel structures, a high grade of material is specified, while the steel used for reinforcing concrete is sometimes made of unsuitable, brittle material.

Faulty execution, careless workmanship and too early removal of forms may generally be attributed to unintelligent or insufficient supervision.

3. RESPONSIBILITY AND SUPERVISION.

The design of reinforced concrete structures should receive at least the same careful consideration as those of steel, and only engineers with sufficient experience and good judgment should be intrusted with such work.

The computations should include all minor details, which are sometimes of the utmost importance. The design should show clearly the size and position of the reinforcement and should provide for proper connection between the component parts, so that they cannot be displaced. As the connection between

reinforced concrete members are frequently a source of weakness, the design should include a detailed study of such connections, accompanied by computations to prove their strength.

While other engineering structures on the safety of which human lives depend are generally designed by engineers employed by the owner, and the contracts let on the engineer's design and specifications, in accordance with legitimate practice, reinforced concrete structures frequently are designed by contractors or by engineers commercially interested, and the contract let for a lump sum.

The construction of buildings in large cities is regulated by ordinances or building laws, and the work is inspected by municipal authorities. For reinforced concrete work, however, the limited supervision which municipal inspectors are able to give is not sufficient. Therefore, means for more adequate supervision and inspection should be provided.

The execution of the work should not be separated from the design, as intelligent supervision and successful execution can be expected only when both functions are combined. The engineer who prepares the design and specifications should have, therefore, the supervision of the execution of the work.

The Committee recommends the following rules for structures of reinforced concrete for the purpose of fixing the responsibility and providing for adequate supervision during construction:

(*a*) Before work is commenced, complete plans shall be prepared, accompanied by specifications, stress computations, and descriptions showing the general arrangement and all details. The plans shall show the size, length, dimensions for points of bending, and exact position of all reinforcement, including stirrups, ties, hooping and splicing. The computations shall give the loads assumed separately, such as dead and live loads, wind and impact, if any, and the resulting stresses.

(*b*) The specifications shall state the qualities of the materials to be used for making the concrete, and the manner in which they are to be proportioned.

(*c*) The strength which the concrete is expected to attain after a definite period shall be stated in the specifications.

(*d*) The drawings and specifications shall be signed by the engineer and the contractor.

(*e*) Plans and specifications for all public structures should be approved by a legally authorized state or city official, and copies of such plans and specifications placed on file in his office.

(*f*) The approval of plans and specifications by other authorities shall not relieve the engineer nor the contractor of responsibility.

(*g*) Inspection during construction shall be made by competent inspectors employed by and under the supervision of the engineer, and shall cover the following:

1. The materials.
2. The correct construction and erection of the forms and the supports.
3. The sizes, shapes and arrangement of the reinforcement.
4. The proportioning, mixing and placing of the concrete.
5. The strength of the concrete by tests of standard test pieces made on the work.
6. Whether the concrete is sufficiently hardened before the forms and supports are removed.
7. Prevention of injury to any part of the structure by and after the removal of the forms.
8. Comparison of dimensions of all parts of the finished structure with the plans.

(*h*) Load tests on portions of the finished structure shall be made where there is reasonable suspicion that the work has not been properly performed, or that, through influences of some kind, the strength has been impaired. Loading shall be carried to such a point that one and three quarters times the calculated working stresses in critical parts are reached, and such loads shall cause no injurious permanent deformations. Load tests shall not be made until after 60 days of hardening.

4. DESTRUCTIVE AGENCIES.

(*a*) *Corrosion of Metal Reinforcement.*—Tests and experience indicate that steel sufficiently embedded in good concrete is well protected against corrosion no matter whether located above or below water level. It is recommended that such protection

be not less than 1 in. in thickness. If the concrete is porous so as to be readily permeable by water, as when the concrete is laid with a very dry consistency, the metal may corrode on account of the presence of moisture and air.

(*b*) *Electrolysis.*—The most recent experimental data available on this subject seem to show that while reinforced concrete structures may, under certain conditions, be injured by the flow of electric current in either direction between the reinforcing material and the concrete, such injury is generally to be expected only where voltages are considerably higher than those which usually occur in concrete structures in practice. If the iron be positive, trouble may manifest itself by corrosion of the iron accompanied by cracking of the concrete, and, if the iron be negative, there may be a softening of the concrete near the surface of the iron, resulting in a destruction of the bond. The former, or anode effect, decreases much more rapidly than the voltage, and almost if not quite disappears at voltages that are most likely to be encountered in practice. The cathode effect, on the other hand, takes place even on very low voltages, and is therefore more important from a practical standpoint than that of the anode.

Structures containing salt or calcium chloride, even in very small quantities, are very much more susceptible to the effects of electric currents than normal concrete, both the anode and cathode effects progressing much more rapidly in the presence of chlorine.

There is great weight of evidence to show that normal reinforced concrete structures free from salt are in very little danger under most practical conditions, while non-reinforced concrete structures are practically immune from electrolysis troubles.

The results of experiments now in progress may yield more conclusive information on the subject.

(*c*) *Sea Water.*—The data available concerning the effect of sea water on concrete or reinforced concrete are limited and inconclusive. Sea walls out of the range of frost action have been standing for many years without apparent injury. In many harbors where the water is brackish, through rivers discharging into them, serious disintegration has taken place. This has occurred chiefly between low and high tide levels and is due, evidently, in part to frost. Chemical action also appears to be indicated by the softening of the mortar. To effect the best

resistance to sea water, the concrete must be proportioned, mixed and placed so as to prevent the penetration of sea water into the mass or through the joints. The cement should be of such chemical composition as will best resist the action of sea water; the aggregates should be carefully selected, graded and proportioned with the cement so as to secure the maximum possible density; the concrete should be thoroughly mixed; the joints between old and new work should be made watertight; and the concrete should be kept from exposure to sea water until it is thoroughly hard and impervious.

(*d*) *Acids.*—Concrete of first class quality thoroughly hardened is affected appreciably only by strong acids which seriously injure other materials. A substance like manure is injurious to green concrete, but after the concrete has hardened thoroughly it resists the action of such acid satisfactorily.

(*e*) *Oils.*—When concrete is properly made and the surface carefully finished and hardened, it resists the action of such mineral oils as petroleum and ordinary engine oils. Oils which contain fatty acids produce injurious effects, forming compounds with the lime which result in a disintegration of the concrete in contact with them.

(*f*) *Alkalies.*—The action of alkalies on concrete is problematical. In the reclamation of arid land where the soil is heavily charged with alkaline salts it has been found that concrete, stone, brick, iron and other materials are injured under certain conditions. It would seem that at the level of the ground water in an extremely dry atmosphere such structures are disintegrated, through the rapid crystallization of the alkaline salts, resulting from the alternate wetting and drying of the surface. Such destructive action can be prevented by the use of a protective coating and is minimized by securing a dense concrete.

III. MATERIALS.

A knowledge of the properties of the materials entering into concrete and reinforced concrete is the first essential. The importance of the quality of the materials used cannot be overestimated, and not only the cement but also the aggregates should be subject to such definite requirements and tests as will insure concrete of the desired quality.

1. CEMENT.

There are available for construction purposes Portland, Natural and Puzzolan or Slag cements. Only Portland cement is suitable for reinforced concrete.

(*a*) *Portland Cement* is the finely pulverized product resulting from the calcination to incipient fusion of an intimate mixture of properly proportioned argillaceous and calcareous materials. It has a definite chemical composition varying within comparatively narrow limits.

Portland cement should be used in reinforced concrete construction and any construction that will be subject to shocks or vibrations or stresses other than direct compression.

(*b*) *Natural Cement* is the finely pulverized product resulting from the calcination of an argillaceous limestone at a temperature only sufficient to drive off the carbonic acid gas. Although the limestone must have a certain composition, this composition may vary within much wider limits than in the case of Portland cement. Natural cement does not develop its strength as quickly nor is it as uniform in composition as Portland cement.

Natural cement may be used in massive masonry where weight rather than strength is the essential feature.

Where economy is the governing factor a comparison may be made between the use of natural cement and a leaner mixture of Portland cement that will develop the same strength.

(*c*) *Puzzolan or Slag Cement* is the finely pulverized product resulting from grinding a mechanical mixture of granulated basic blast furnace slag and hydrated lime.

Puzzolan cement is not nearly as strong, uniform or reliable as Portland or natural cement, is not used extensively and never in important work; it should be used only for foundation work underground where it is not exposed to air or running water.

(*d*) *Specifications.*—The cement should meet the requirements of the Standard Methods of Testing and Specifications for Cement (see Appendix, p. 274), or as may be hereafter amended, the result of the joint labors of special committees of the American Society of Civil Engineers, American Society for Testing Materials, American Railway Engineering Association, and others.

2. AGGREGATES.

Extreme care should be exercised in selecting the aggregates for mortar and concrete, and careful tests made of the materials for the purpose of determining their qualities and the grading necessary to secure maximum density[1] or a minimum percentage of voids.

(*a*) *Fine Aggregate* should consist of sand, crushed stone, or gravel screening, graded from fine to coarse and passing when dry a screen having $\frac{1}{4}$-in. diameter holes; it preferably should be of siliceous material, and should be clean, coarse, free from dust, soft particles, vegetable loam or other deleterious matter and not more than 6 per cent should pass a sieve having 100 meshes per linear inch. Fine aggregates should always be tested.

Fine aggregates should be of such quality that mortar composed of one part Portland cement and three parts fine aggregate by weight when made into briquettes will show a tensile strength at least equal to the strength of 1:3 mortar of the same consistency made with the same cement and standard Ottawa sand.[2] If the aggregate be of poorer quality the proportion of cement should be increased in the mortar to secure the desired strength.

If the strength developed by the aggregate in the 1:3 mortar is less than 70 per cent of the strength of the Ottawa-sand mortar, the material should be rejected. To avoid the removal of any coating on the grains, which may affect the strength, bank sands should not be dried before being made into mortar, but should contain natural moisture. The percentage of moisture may be determined upon a separate sample for correcting weight. From 10 to 40 per cent more water may be required in mixing bank or artificial sands than for standard Ottawa sand to produce the same consistency.

(*b*) *Coarse Aggregate* should consist of crushed stone or gravel which is retained on a screen having $\frac{1}{4}$-in. diameter holes and graded from the smallest to the largest particles; it should be clean, hard, durable, and free from all deleterious matter. Aggregates containing dust and soft, flat or elongated particles, should be excluded from important structures.

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[1] A convenient coefficient of density is the ratio of the sum of the volumes of materials contained in a unit volume to the total unit volume.

[2] A natural sand obtained at Ottawa, Illinois, passing a screen having 20 meshes and retained on a screen having 30 meshes per linear inch; prepared and furnished by the Ottawa Silica Company, for 2 cents per pound f. o. b. cars, Ottawa, Illinois—under the direction of the Special Committee on Uniform Tests of Cement of the American Society of Civil Engineers.

The maximum size of the coarse aggregate is governed by the character of the construction.

For reinforced concrete and for small masses of unreinforced concrete, the aggregate must be small enough to produce with the mortar a homogeneous concrete of viscous consistency which will pass readily between and easily surround the reinforcement and fill all parts of the forms.

For concrete in large masses the size of the coarse aggregate may be increased, as a large aggregate produces a stronger concrete than a fine one, although it should be noted that the danger of separation from the mortar becomes greater as the size of the coarse aggregate increases.

Cinder concrete should not be used for reinforced concrete structures. It may be allowable in mass for very light loads or for fire protection purposes. The cinders used should be composed of hard, clean, vitreous clinker, free from sulphides, unburned coal or ashes.

3. WATER.

The water used in mixing concrete should be free from oil, acid, alkalies, or organic matter.

4. METAL REINFORCEMENT.

The Committee recommends as a suitable material for reinforcement, steel filling the requirements for structural steel reinforcement of the specifications adopted by the American Railway Engineering Association (Appendix, p. 274).

Where little bending or shaping is required, and also for reinforcement for shrinkage and temperature stresses, material filling the requirements of the specifications adopted by the American Railway Engineering Association for high-carbon steel (Appendix, p. 274) may be used, adopting the same unit stresses as hereinafter recommended for structural grade material.

For the reinforcement of slabs, small beams or minor details, or for reinforcement for shrinkage and temperature stresses, wire drawn from bars of the grade of rivet steel may be used, with the unit stresses hereinafter recommended.

The reinforcement should be free from excessive rust, scale,

or coatings of any character which would tend to reduce or destroy the bond.

IV. PREPARING AND PLACING MORTAR AND CONCRETE.

1. PROPORTIONS.

The materials to be used in concrete should be carefully selected, of uniform quality, and proportioned with a view to securing as nearly as possible a maximum density.

(*a*) *Unit of Measure.*—The unit of measure should be the cubic foot. A bag of cement, containing 94 lb. net, should be considered the equivalent of one cubic foot.

The measurement of the fine and coarse aggregates should be by loose volume.

(*b*) *Relation of Fine and Coarse Aggregates.*—The fine and coarse aggregates should be used in such relative proportions as will insure maximum density. In unimportant work it is sufficient to do this by individual judgment, using correspondingly higher proportions of cement; for important work these proportions should be carefully determined by density experiments and the sizing of the fine and coarse aggregates should be uniformly maintained or the proportions changed to meet the varying sizes.

(*c*) *Relation of Cement and Aggregates*.—For reinforced concrete construction, one part of cement to a total of six parts of fine and coarse aggregates measured separately should generally be used. For columns, richer mixtures are generally preferable, and in massive masonry or rubble concrete a mixture of 1:9 or even 1:12 may be used.

These proportions should be determined by the strength or the wearing qualities required in the construction at the critical period of its use. Experienced judgment based on individual observation and tests of similar conditions in similar localities is an excellent guide as to the proper proportions for any particular case.

For all important construction, advance tests should be made of concrete of the materials, proportions and consistency to be used in the work. These tests should be made under laboratory conditions to obtain uniformity in mixing, proportioning and storage, and in case the results do not conform to the requirements of the work, aggregates of a better quality should be chosen or richer proportions used to obtain the desired results.

2. MIXING.

The ingredients of concrete should be thoroughly mixed and the mixing should continue until the cement is uniformly distributed and the mass is uniform in color and homogeneous. As the maximum density and greatest strength of a given mixture depend largely on thorough and complete mixing, it is essential that the work of mixing should receive special attention and care.

Inasmuch as it is difficult to determine, by visual inspection, whether the concrete is uniformly mixed, especially where limestone or aggregates having the color of cement are used, it is essential that the mixing should occupy a definite period of time. The minimum time will depend on whether the mixing is done by machine or hand.

(*a*) *Measuring Ingredients.*—Methods of measurement of the proportions of the various ingredients should be used which will secure separate and uniform measurements of cement, fine aggregate, coarse aggregate, and water at all times.

(*b*) *Machine Mixing.*—When the conditions will permit, a machine mixer of a type which insures the uniform proportioning of the materials throughout the mass should be used, as a more uniform consistency can be thus obtained. The mixing should continue for a minimum time of at least one minute after all the ingredients are assembled in the mixer.

(*c*) *Hand Mixing.*—When it is necessary to mix by hand, the mixing should be on a water-tight platform and especial precautions should be taken to turn all the ingredients together at least six times and until they are homogeneous in appearance and color.

(*d*) *Consistency.*—The materials should be mixed wet enough to produce a concrete of such a consistency as will flow into the forms and about the metal reinforcement when used, and which, at the same time, can be conveyed from the mixer to the forms without separation of the coarse aggregate from the mortar.

(*e*) *Retempering.*—Mortar or concrete should not be remixed with water after it has partly set.

3. PLACING CONCRETE.

(*a*) *Methods.*—Concrete after the completion of the mixing should be handled rapidly, and in as small masses as is practicable,

from the place of mixing to the place of final deposit, and under no circumstances should concrete be used that has partly set. A slow-setting cement should be used when a long time is likely to occur between mixing and placing.

Concrete should be deposited in such a manner as will permit the most thorough compacting, such as can be obtained by working with a straight shovel or slicing tool kept moving up and down until all the ingredients have settled in their proper place by gravity and the surplus water has been forced to the surface. Special care should be exercised to prevent the formation of laitance, which hardens very slowly and forms a poor surface on which to deposit fresh concrete. All laitance should be removed.

Before depositing concrete, the reinforcement should be carefully placed in accordance with the plans, and adequate means provided to hold it in its proper position until the concrete has been deposited and compacted; care should be taken to see that the forms are substantial and thoroughly wetted (except in freezing weather) or oiled and that the space to be occupied by the concrete is free from débris. When the placing of concrete is suspended, all necessary grooves for joining future work should be made before the concrete has had time to set.

When work is resumed, concrete previously placed should be roughened, thoroughly cleansed of foreign material and laitance, thoroughly wetted and then slushed with a mortar consisting of one part Portland cement and not more than two parts fine aggregate.

The faces of concrete exposed to premature drying should be kept wet for a period of at least seven days.

(*b*) *Freezing Weather.*—Concrete should not be mixed or deposited at a freezing temperature, unless special precautions are taken to avoid the use of materials covered with ice crystals or containing frost, and to provide means to prevent the concrete from freezing after being placed in position and until it has thoroughly hardened.

As the coarse aggregate forms the greater portion of the concrete, it is particularly important that this material be heated to well above the freezing point.

(*c*) *Rubble Concrete.*—Where the concrete is to be deposited in massive work, its value may be improved and its cost mate-

rially reduced by the use of clean stones thoroughly embedded in the concrete as near together as is possible and still entirely surrounded by concrete.

(*d*) *Under Water.*—In placing concrete under water it is essential to maintain still water at the place of deposit. The use of tremies, properly designed and operated, is a satisfactory method of placing concrete through water. The concrete should be mixed very wet (more so than is ordinarily permissible) so that it will flow readily through the tremie and into the place with practically a level surface.

The coarse aggregate should be smaller than ordinarily used, and never more than 1 in. in diameter. The use of gravel facilitates mixing and assists the flow of concrete through the tremie. The mouth of the tremie should be buried in the concrete so that it is at all times entirely sealed and the surrounding water prevented from forcing itself into the tremie; the concrete will then discharge without coming in contact with the water. The tremie should be suspended so that it can be lowered quickly when it is necessary either to choke off or prevent too rapid flow; the lateral flow should preferably be not over 15 ft.

The flow should be continuous in order to produce a monolithic mass and to prevent the formation of laitance in the interior.

In large structures it may be necessary to divide the mass of concrete into several small compartments or units, filling one at a time. With proper care it is possible in this manner to obtain as good results under water as in the air.

V. FORMS.

Forms should be substantial and unyielding, so that the concrete shall conform to the designed dimensions and contours, and should be tight in order to prevent the leakage of mortar.

The time for removal of forms is one of the most important steps in the erection of a structure of concrete or reinforced concrete. Care should be taken to inspect the concrete and ascertain its hardness before removing the forms.

So many conditions affect the hardening of concrete, that the proper time for the removal of the forms should be decided by some competent and responsible person, especially where the atmospheric conditions are unfavorable.

It may be stated in a general way that forms should remain in place longer for reinforced concrete than for plain or massive concrete, and that forms for floors, beams and similar horizontal structures should remain in place much longer than for vertical walls.

When the concrete gives a distinctive ring under the blow of a hammer, it is generally an indication that it has hardened sufficiently to permit the removal of the forms with safety. If, however, the temperature is such that there is any possibility that the concrete is frozen, this test is not a safe reliance, as frozen concrete may appear to be very hard.

VI. DETAILS OF CONSTRUCTION.

1. JOINTS.

(*a*) *Concrete.*—For concrete construction it is desirable to cast the entire structure at one operation, but as this is not always possible, especially in large structures, it is necessary to stop the work at some convenient point. This should be selected so that the resulting joint may have the least possible effect on the strength of the structure. It is therefore recommended that the joint in columns be made flush with the lower side of the girders; that the joints in girders be at a point midway between supports, but should a beam intersect a girder at this point, the joint should be offset a distance equal to twice the width of the beam; that the joints in the members of a floor system should in general be made at or near the center of the span.

Joints in columns should be perpendicular to the axis of the column, and in girders, beams, and floor slabs, perpendicular to the plane of their surfaces.

Girders should never be constructed over freshly formed columns without permitting a period of at least two hours to elapse, thus providing for settlement or shrinkage in the columns.

Shrinkage and contraction joints may be necessary in concrete subject to great fluctuations in temperature. The frequency of these joints will depend, first, on the range of temperature to which the concrete will be subjected, and second, on the quantity and position of the reinforcement, These joints should be determined and provided for in the design. In massive work, such as retaining walls, abutments, etc., built without rein-

forcement, contraction joints should be provided, at intervals of from 25 to 50 ft. and with reinforcement from 50 to 80 ft. (the smaller the height and thickness, the closer the spacing), throughout the length of the structure. To provide against the structures being thrown out of line by unequal settlement, each section of the wall should be tongued and grooved into the adjoining section. A groove should be formed in the surface of the concrete at vertical joints in walls or abutments.

Shrinkage and contraction joints should be lubricated by either an application of petroleum residuum oil or a similar material so as to permit a free movement at the joint when the concrete expands or contracts.

The insertion of a sheet of copper or zinc or even tarred paper will be found advantageous securing expansion and contraction at the joint.

(*b*) *Reinforcement.*—Wherever it is necessary to splice tension reinforcement the length of lap should be determined on the basis of the safe bond stress, the stress in the bar and the shearing resistance of the concrete at the point of splice; or a connection should be made between the bars of sufficient strength to carry the stress. Splices at points of maximum stress should be avoided. In columns, bars more than $\frac{3}{4}$ in. in diameter not subject to tension should be properly squared and butted in a suitable sleeve; smaller bars may be treated as indicated for tension reinforcement or the stress may be cared for by embedment in large masses of concrete. At foundations, bearing plates should be provided for supporting the bars, or the bars may be carried into the footing a sufficient distance to transmit the stress of the steel to the concrete by means of the bearing and bond resistance; in no case shall the ends of the bars be permitted merely to rest on concrete.

2. SHRINKAGE AND TEMPERATURE CHANGES.

Shrinkage of concrete, due to hardening and contraction from temperature changes, causes cracks, the size of which depends on the extent of the mass. The resulting stresses are important in monolithic construction and should be considered carefully by the designer; they cannot be counteracted successfully, but the effects can be minimized.

Large cracks produced by quick hardening or wide ranges of temperature can be broken up to some extent into small cracks by placing reinforcement in the concrete; in long continuous lengths of concrete, it is better to provide shrinkage joints at points in the structure where they will do little or no harm. Reinforcement is of assistance and permits longer distances between shrinkage joints than when no reinforcement is used.

Small masses or thin bodies of concrete should not be joined to larger or thicker masses without providing for shrinkage at such points. Fillets similar to those used in metal castings, but of larger dimensions, for gradually reducing from the thicker to the thinner body, are of advantage.

Shrinkage cracks are likely to occur at points where fresh concrete is joined to that which is set, and hence in placing the concrete, construction joints should be made on horizontal and vertical lines, and, if possible, at points where joints would naturally occur in dimension stone masonry.

3. FIREPROOFING.

The actual fire tests of concrete and reinforced concrete have been limited, but experience, together with the results of tests thus far made, indicates that concrete, on account of its low rate of heat conductivity and the fact that it is incombustible, may be used safely for fireproofing purposes.

The dehydration of concrete probably begins at about 500° F. and is completed at about 900° F., but experience indicates that the volatilization of the water absorbs heat from the surrounding mass, which, together with the resistance of the air cells, tends to increase the heat resistance of the concrete, so that the process of dehydration is very much retarded. The concrete that is actually affected by fire remains in position and affords protection to the concrete beneath it.

The thickness of the protective coating required depends on the probable duration of a fire which is likely to occur in the structure and should be based on the rate of heat conductivity. The question of the conductivity of concrete is one which requires further study and investigation before a definite rate for different classes of concrete can be fully established.

However, for ordinary conditions it is recommended that the metal in girders and columns be protected by a minimum of 2 in. of concrete; that the metal in beams be protected by a minimum of $1\frac{1}{2}$ in. of concrete, and that the metal in floor slabs be protected by a minimum of 1 in. of concrete.

It is recommended that in monolithic concrete columns, the concrete to a depth of $1\frac{1}{2}$ in. be considered as protective covering and not included in the effective section.

It is recommended that the corners of columns, girders and beams be beveled or rounded, as a sharp corner is more seriously affected by fire than a round one.

4. WATERPROOFING.

Many expedients have been used to render concrete impervious to water under normal conditions, and also under pressure conditions that exist in reservoirs, dams and conduits of various kinds. Experience shows, however, that where mortar or concrete is proportioned to obtain the greatest practicable density and is mixed to a rather wet consistency, the resulting mortar or concrete is impervious under moderate pressure.

A concrete of dry consistency is more or less pervious to water, and compounds of various kinds have been mixed with the concrete, or applied as a wash to the surface for the purpose of making it water tight. Many of these compounds are of but temporary value, and in time lose their power of imparting impermeability to the concrete.

In the case of subways, long retaining walls and reservoirs, provided the concrete itself is impervious, cracks may be so reduced by horizontal and vertical reinforcement properly proportioned and located, that they are too minute to permit leakage, or are soon closed by infiltration of silt.

Coal-tar preparations applied either as a mastic or as a coating on felt or cloth fabric, are used for waterproofing, and should be proof against injury by liquids or gases.

For retaining and similar walls in direct contact with the earth, the application of one or two coatings of hot coal-tar pitch to the thoroughly dried surface of concrete is an efficient method of preventing the penetration of moisture from the earth.

5. SURFACE FINISH.

Concrete is a material of an individual type and should not be used in imitation of other structural materials. One of the important problems connected with its use is the character of the finish of exposed surfaces. The finish of the surface should be determined before the concrete is placed, and the work conducted so as to make possible the finish desired. For many forms of construction the natural surface of the concrete is unobjectionable, but frequently the marks of the boards and the flat dead surface are displeasing, making some special treatment desirable. A treatment of the surface either by scrubbing it while green or by tooling it after it is hard, which removes the film of mortar and brings the aggregates of the concrete into relief, is frequently used to remove the form markings, break the monotonous appearance of the surface, and make it more pleasing. The plastering of surfaces should be avoided, for even if carefully done, it is likely to peel off under the action of frost or temperature changes.

VII. DESIGN.

1. MASSIVE CONCRETE.

In the design of massive or plain concrete, no account should be taken of the tensile strength of the material, and sections should usually be proportioned so as to avoid tensile stresses except in slight amounts to resist indirect stresses. This will generally be accomplished, in the case of rectangular shapes, if the line of pressure is kept within the middle third of the section, but in very large structures, such as high masonry dams, a more exact analysis may be required. Structures of massive concrete are able to resist unbalanced lateral forces by reason of their weight; hence the element of weight rather than strength often determines the design. A relatively cheap and weak concrete, therefore, will often be suitable for massive concrete structures.

It is desirable generally to provide joints at intervals to localize the effect of contraction.

Massive concrete is suitable for dams, retaining walls, and piers and short columns in which the ratio of length to least

width is relatively small. Under ordinary conditions this ratio should not exceed six. It is also suitable for arches of moderate span, where the conditions as to foundations are favorable.

2. REINFORCED CONCRETE.

By the use of metal reinforcement to resist the principal tensile stresses, concrete becomes available for general use in a great variety of structures and structural forms. This combination of concrete and metal is particularly advantageous in the beam where both compression and tension exist; it is also advantageous in the column where the main stresses are compressive, but where cross-bending may exist. The theory of design, therefore, will relate mainly to the analysis of beams and columns.

3. GENERAL ASSUMPTIONS.

(*a*) *Loads.*—The loads or forces to be resisted consist of:

1. *The dead load*, which includes the weight of the structure and fixed loads and forces.
2. *The live load* or the loads and forces which are variable. The dynamic effect of the live load will often require consideration. Any allowance for the dynamic effect is preferably taken into account by adding the desired amount to the live load or to the live load stresses. The working stresses hereinafter recommended are intended to apply to the equivalent static stresses thus determined.

   In the case of high buildings the live load on columns may be reduced in accordance with the usual practice.

(*b*) *Lengths of Beams and Columns.*—The span length for beams and slabs shall be taken as the distance from center to center of supports, but need not be taken to exceed the clear span plus the depth of beam or slab. Brackets shall not be considered as reducing the clear span in the sense here intended.

The length of columns shall be taken as the maximum unsupported length.

(*c*) *Internal Stresses.*—As a basis for calculations relating to

the strength of structures, the following assumptions are recommended:

1. Calculations will be made with reference to working stresses and safe loads rather than with reference to ultimate strength and ultimate loads.
2. A plane section before bending remains plane after bending.
3. The modulus of elasticity of concrete in compression within the usual limits of working stresses, is constant. The distribution of compressive stresses in beams therefore is rectilinear.
3. In calculating the moment of resistance of beams the tensile stresses in the concrete are neglected.
5. Perfect adhesion is assumed between concrete and reinforcement. Under compressive stresses the two materials are therefore stressed in proportion to their moduli of elasticity.
6. The ratio of the modulus of elasticity of steel to the modulus of elasticity of concrete is taken at 15 except as modified in Chapter VIII, Section 8.
7. Initial stress in the reinforcement due to contraction or expansion in the concrete is neglected.

It is recognized that some of the assumptions given herein are not entirely borne out by experimental data. They are given in the interest of simplicity and uniformity, and variations from exact conditions are taken into account in the selection of formulas and working stresses.

The deflection of beams is affected by the tensile strength developed throughout the length of the beam. For calculations of deflections a value of 8 for the ratio of the moduli will give results corresponding approximately with the actual conditions.

4. T-BEAMS.

In beam and slab construction, an effective bond should be provided at the junction of the beam and slab. When the principal slab reinforcement is parallel to the beam, transverse reinforcement should be used extending over the beam and well into the slab.

Where adequate bond and shearing resistance between slab and web of beam is provided, the slab may be considered as an integral part of the beam, but its effective width shall be determined by the following rules:

(*a*) It shall not exceed one-fourth of the span length of the beam;

(*b*) Its overhanging width on either side of the web shall not exceed four times the thickness of the slab.

In the design of T-beams acting as continuous beams, due consideration should be given to the compressive stresses at the support.

Beams in which the T-form is used only for the purpose of providing additional compression area of concrete should preferably have a width of flange not more than three times the width of the stem and a thickness of flange not less than one-third of the depth of the beam. Both in this form and in the beam and slab form the web stresses and the limitations in placing and spacing the longitudinal reinforcement will probably be controlling factors in design.

5. FLOOR SLABS.

Floor slabs should be designed and reinforced as continuous over the supports. If the length of the slab exceeds 1.5 times its width the entire load should be carried by transverse reinforcement. Square slabs may well be reinforced in both directions.[1]

[1] The exact distribution of load on square and rectangular slabs, supported on four sides and reinforced in both directions cannot readily be determined. The following method of calculation is recognized to be faulty, but it is offered as a tentative method which will give results on the safe side.[1] The distribution of load is first to be determined by the formula

$$r = \frac{l^4}{l^4 + b^4}$$

in which r = proportion of load carried by the transverse reinforcement, l = length and b = breadth of slab. For various ratio of l/b the values of r are as follows:

l/b	r
1	0.50
1.1	0.59
1.2	0.67
1.3	0.75
1.4	0.80
1.5	0.83

Using the values above specified each set of reinforcement is to be calculated in the same manner as slabs having supports on two sides only, but the total amount of reinforcement thus determined may be reduced 25 per cent, by gradually increasing the rod spacing from the third point to the edge of the slab.

The continuous flat slab with multiple-way reinforcement is a type of construction used quite extensively, which has recognized advantages for special conditions, as in the case of warehouses with large, open floor space. At present a considerable difference of opinion exists among engineers as to the formulas and constants which should be used, but experience and tests are accumulating data which it is hoped will in the near future permit the formulation of the principles of design for this form of construction.

The loads carried to beams by slabs which are reinforced in two directions will not be uniformly distributed to the supporting beam and its distribution will depend on the relative stiffness of the slab and the supporting beam. The distribution under ordinary conditions of construction may be expected to be that in which the load on the beam varies in accordance with the ordinates of a parabola having its vertex at the middle of the span. For any given design, the probable distribution should be ascertained and the moments in the beam calculated accordingly.

6. CONTINUOUS BEAMS AND SLABS.

When the beam or slab is continuous over its supports, reinforcement should be fully provided at points of negative moment, and the stresses in concrete recommended in Chapter VIII, Section 4, should not be exceeded. In computing the positive and negative moments in beams and slabs continuous over several supports, due to uniformly distributed loads, the following rules are recommended:

(*a*) That for floor slabs the bending moments at center and at support be taken at $\frac{wl^2}{12}$ for both dead and live loads, where w represents the load per linear foot and l the span length.

(*b*) That for beams the bending moment at center and at support for interior spans be taken at $\frac{wl^2}{12}$, and for ends spans it be taken at $\frac{wl^2}{10}$ for center and adjoining support, for both dead and live loads.

(*c*) In the case of beams and slabs continuous for two spans only, the bending moment at the central support should be taken as $\frac{wl^2}{8}$ and near the middle of the span as $\frac{wl^2}{10}$.

(*d*) At the ends of continuous beams, the amount of negative moment which will be developed will depend on the condition of restraint or fixedness, and this will depend on the form of construction used. There will usually be some restraint and there is likely to be considerable. Provision should be made for the negative bending moment, but as its amount will depend on the form of construction the coefficient cannot be specified here and must be left to the judgment of the designer.

For spans of unusual length, more exact calculations should be made. Special consideration is also required in the case of concentrated loads.

Even if the center of the span is designed for a greater bending moment than is called for by (*a*) or (*b*), the negative moment at the support should not be taken as less than the values there given.

Where beams are reinforced on the compression side, the steel may be assumed to carry its proportion of stress in accordance with the provisions of Chapter VII, Section 3, c-6. In the case of cantilever and continuous beams, tensile and compressive reinforcement over supports must extend sufficiently beyond the support and beyond the point of infection to develop the requisite bond strength.

7. BOND STRENGTH AND SPACING OF REINFORCEMENT.

Adequate bond strength should be provided. The formula hereinafter given for bond stresses in beams is for straight longitudinal bars. In beams in which a portion of the reinforcement is bent up near the end, the bond stress at places in both the straight bars and the bent bars will be considerably greater than for all the bars straight, and the stress at some point may be several times as much as that found by considering the stress to be uniformly distributed along the bar. In restrained and canti-

lever beams full tensile stress exists in the reinforcing bars at the point of support and the bars must be anchored in the support sufficiently to develop this stress.

In case of anchorage of bars, an additional length of bar must be provided beyond that found on the assumption of uniform bond stress, for the reason that before the bond resistance at the end of the bar can be developed the bar may have begun to slip at another point and "running" resistance is less than the resistance before slip begins.

Where high bond resistance is required, the deformed bar is a suitable means of supplying the necessary strength. But it should be recognized that even with a deformed bar initial slip occurs at early loads, and that the ultimate loads obtained in the usual tests for bond resistance may be misleading. Adequate bond strength throughout the length of a bar is preferable to end anchorage, but, as an additional safeguard, such anchorage may properly be used in special cases. Anchorage furnished by short bends at a right angle is less effective than hooks consisting of turns through 180 deg.

The lateral spacing of parallel bars should not be less than three diameters, from center to center, nor should the distance from the side of the beam to the center of the nearest bar be less than two diameters. The clear spacing between two layers of bars should not be less than 1 in. The use of more than two layers is to be discouraged, unless the layers are tied together by adequate metal connections, particularly at and near points where bars are bent up or bent down.

8. DIAGONAL TENSION AND SHEAR.

When a reinforced concrete beam is subjected to flexural action, diagonal tensile stresses are set up. If, in a beam not having web reinforcement, these stresses exceed the tensile strength of the concrete, failure of the beam will ensue. When web reinforcement made up of stirrups or of diagonal bars secured to the longitudinal reinforcement, or of longitudinal reinforcing bars bent up at several points is used, new conditions prevail, but even in this case at the beginning of loading the diagonal tension developed is taken principally by the concrete, the deformations which are developed in the concrete permitting but little stress to be taken

by the web reinforcement. When the resistance of the concrete to the diagonal tension is overcome at any point in the depth of the beam, greater stress is at once set up in the web reinforcement.

For homogeneous beams the analytical treatment of diagonal tension is not very complex—the diagonal tensile stress is a function of the horizontal and vertical shearing stresses and of the horizontal tensile stress at the point considered, and as the intensity of these three stresses varies from the neutral axis to the remotest fiber, the intensity of the diagonal tension will be different at different points in the section and will change with different proportionate dimensions of length to depth of beam. For the composite structure of reinforced concrete beams, an analysis of the web stresses, and particularly of the diagonal tensile stresses, is very complex; and when the variations due to a change from no horizontal tensile stress in the concrete at remotest fiber to the presence of horizontal tensile stress at some point below the neutral axis are considered, the problem becomes more complex and indefinite. Under these circumstances, in designing, recourse is had to the use of the calculated vertical shearing stress as a means of comparing or measuring the diagonal tensile stresses developed, it being understood that the vertical shearing stress is not the numerical equivalent of the diagonal tensile stress and even that there is not a constant ratio between them. It is here recommended that the maximum vertical shearing stress in a section be used as the means of comparison of the resistance to diagonal tensile stress developed in the concrete in beams not having web reinforcement.

Even after the concrete has reached its limit of resistance to diagonal tension, if the beam has web reinforcement, conditions of beam action will continue to prevail at least through the compression area, and the web reinforcement will be called on to resist only a part of the web stresses. From experiments with beams it is concluded that it is safe practice to use only two-thirds of the external vertical shear in making calculations of the stresses that come on stirrups, diagonal web pieces, and bent-up bars, and it is here recommended for calculations in designing that two-thirds of the external vertical shear be taken as producing stresses in web reinforcement.

Experiments bearing on the design of details of web rein-

forcement are not yet complete enough to allow more than general and tentative recommendations to be made. It is well established, however, that vertical members attached to or looped about horizontal members, inclined members secured to horizontal members in such a way as to insure against slip, and the bending of a part of the longitudinal reinforcement at an angle, will increase the strength of a beam against failure by diagonal tension, and that a well-designed and well-distributed web reinforcement may under the best conditions increase the total vertical shear carried to a value as much as three times that obtained when the bars are all horizontal and no web reinforcement is used. Where vertical stirrups are used without being secured to the longitudinal reinforcement, the force transmitted between longitudinal bar and stirrup must not be greater than can be taken through the concrete, and care must be taken to provide for the larger bond stress developed in the longitudinal bars with this construction than exists in the absence of stirrups. Sufficient bond resistance between the concrete and the stirrups or diagonals must be provided. Where the longitudinal bars are bent up, the points of bending of the several bars should be distributed along a portion of the length of the beam in such a way as to give efficient web reinforcement over the portion of the length of the beam in which it is needed. The higher resistance to diagonal tension failures given by unit frames having the stirrups and bent-up bars securely connected together both longitudinally and laterally is worthy of recognition. It is necessary that a limit be placed on the amount of shear which may be allowed in a beam; for when web reinforcement sufficiently efficient to give very high web resistance is used, at the higher stresses the concrete in the beam becomes checked and cracked in such a way as to endanger its durability as well as its strength.

The section to be taken as the critical section in the calculation of shearing stresses will generally be the one having the maximum vertical shear, though experiments show that the section at which diagonal tension failures occur is not just at a support even though the shear at the latter point be much greater.

The longitudinal spacing of stirrups or diagonal members or the distribution of the points of bending of adjacent bent-up bars should not exceed three-fourths the depth of the beam.

It is important that adequate bond strength or anchorage be provided to develop fully the assumed strength of all web reinforcement.

It should be noted that it is on the tension side of a beam that diagonal tension develops in a critical way, and that the proper connection must always be made between stirrups or other web reinforcement and the longitudinal tension reinforcement, whether the latter is on the lower side of the beam or on its upper side. Where negative moment exists, as is the case near the supports in a continuous beam, web reinforcement to be effective must be looped over or wrapped around or be connected with the longitudinal tension reinforcing bars at the top of the beam in the same way as is necessary at the bottom of the beam at sections where the bending moment is positive and the tension reinforcing bars are at the bottom of the beam.

Inasmuch as the smaller the longitudinal deformations in the horizontal reinforcement are, the less the tendency for the formation of diagonal cracks, a beam will be strengthened against diagonal tension failure by so arranging and proportioning the horizontal reinforcement that the unit stresses at points of large shear shall be relatively low.

Where pure shearing stress occurs, or shearing stress combined with but a small amount of tensile stress in the concrete, as when a concentrated load rests on a slab or other forms of punching shear are produced, or in the case of compression pieces, the element of tension will not need consideration, and the permissible limit of the shearing stress will be higher than the allowable limit when this stress is used as a means of comparing diagonal tensile stress. The working values recommended are given in Chapter VIII, Working Stresses.

9. COLUMNS.

By columns are meant compression members of which the ratio of unsupported length to least width exceeds about six, and which are provided with reinforcement of one of the forms hereafter described.

It is recommended that the ratio of unsupported length of column to its least width be limited to 15.

The effective area of the column shall be taken as the area

within the protective covering, as defined an Chapter VI, Section 3, or in the case of hooped columns or columns reinforced with structural shapes it shall be taken as the area within the hooping or structural shapes.

Columns may be reinforced by longitudinal bars, by bands, hoops, or spirals, together with longitudinal bars, or by structural forms which in themselves are sufficiently rigid to act as columns. The general effect of closely spaced hooping is greatly to increase the "toughness" of the column and its ultimate strength, but hooping has little effect on its behavior within the limit of elasticity. It thus renders the concrete a safer and more reliable material and should permit the use of a somewhat higher working stress. The beneficial effects of "toughening" are adequately provided by a moderate amount of hooping, a larger amount serving mainly to increase the ultimate strength and the possible deformation before ultimate failure.

Composite columns of structural steel and concrete in which the steel forms a column by itself should be designed with caution. To classify this type as a concrete column reinforced with structural steel is hardly permissible, as the steel will generally take the greater part of the load. When this type of column is used the concrete should not be relied on to tie the steel units together or to transmit stresses from one unit to another. The units should be adequately tied together by tie plates or lattice bars, which, together with other details, such as splices, etc., should be designed in conformity with standard practice for structural steel. The concrete may exert a beneficial effect in restraining the steel from lateral deflection and also in increasing the carrying capacity of the column. The proportion of load to be carried by the concrete will depend on the form of the column and the method of construction. Generally for high percentages of steel the concrete will develop relatively low unit-stresses, and caution should be used in placing dependence on the concrete.

The following recommendations are made for the relative working stresses in the concrete for the several types of columns:

(*a*) Columns with longitudinal reinforcement only, to the extent of not less than 1 per cent and not more

than 4 per cent of the unit stress recommended for axial compression in Chapter VIII, Section 3.

(*b*) Columns with reinforcement of bands, hoops or spirals hereinafter specified, stresses 20 per cent higher than given for (*a*), provided the ratio of unsupported length of column to diameter of the hooped core is not more than 8.

(*c*) Columns reinforced with not less than 1 per cent and not more than 4 per cent of longitudinal bars and with bands, hoops or spirals, as hereinafter specified; stresses 45 per cent higher than given for (*a*), provided the ratio of unsupported length of column to diameter of the hooped core is not more than 8.

The foregoing recommendations are based on the following conditions:

In all cases longitudinal reinforcement is assumed to carry its proportion of stress in accordance with Section 3. The hoops or bands are not to be counted on directly as adding to the strength of the column.

Bars composing longitudinal reinforcement shall be straight and shall have sufficient lateral support to be securely held in place until the concrete has set.

Where hooping is used, the total amount of such reinforcement shall be not less than 1 per cent of the volume of the column, enclosed. The clear spacing of such hooping shall be not greater than one-sixth the diameter of the enclosed column and preferably not greater than one-tenth, and in no case more than $2\frac{1}{2}$ in. Hooping is to be circular and the ends of bands must be united in such a way as to develop their full strength. Adequate means must be provided to hold bands or hoops in place so as to form a column, the core of which shall be straight and well centered. The strength of hooped columns depends very much upon the ratio of length to diameter of hooped core, and the strength due to hooping decreases rapidly as this ratio increases beyond five. The working stresses recommended are for hooped columns with a length of not more than eight diameters of the hooped core.

Bending stresses due to eccentric loads and lateral forces must be provided for by increasing the section until the maximum stress does not exceed the values above specified; and

where tension is possible in the longitudinal bars adequate connection between the ends of the bars must be provided to take this tension.

10. REINFORCING FOR SHRINKAGE AND TEMPERATURE STRESSES.

When areas of concrete too large to expand and contract freely as a whole are exposed to atmospheric conditions, the changes of form due to shrinkage (resulting from hardening) and to action of temperature are such that cracks may occur in the mass, unless precautions are taken to distribute the stresses so as to prevent the cracks altogether or to render them very small. The distance apart of the cracks, and consequently their size, will be directly proportional to the diameter of the reinforcement and to the tensile strength of the concrete, and inversely proportional to the percentage of reinforcement and also to its bond resistance per unit of surface area. To be most effective, therefore, reinforcement (in amount generally not less than one-third of one per cent) of a form which will develop a high bond resistance should be placed near the exposed surface and be well distributed. The allowable size and spacing of cracks depends on various considerations, such as the necessity for water-tightness, the importance of appearance of the surface, and the atmospheric changes.

VIII. WORKING STRESSES.

1. GENERAL ASSUMPTIONS.

The following working stresses are recommended for static loads. Proper allowances for vibration and impact are to be added to live loads where necessary to produce an equivalent static load before applying the unit stresses in proportioning parts.

In selecting the permissible working stress to be allowed on concrete, we should be guided by the working stresses usually allowed for other materials of construction, so that all structures of the same class but composed of different materials may have approximately the same degree of safety.

The following recommendations as to allowable stresses are given in the form of percentages of the ultimate strength of the particular concrete which is to be used; this ultimate strength is

to be that developed in cylinders 8 in. in diameter and 16 in. long, of the consistency described in Chapter IV, Section 2 (*a*), made and stored under laboratory conditions, at an age of 28 days. In the absence of definite knowledge in advance of construction as to just what strength may be expected, the Committee submits the following values as those which should be obtained with materials and workmanship in accordance with the recommendations of this report.

Although occasional tests may show higher results than those here given, the Committee recommends that these values should be the maximum used in design.

TABLE OF STRENGTHS OF DIFFERENT MIXTURES OF CONCRETE.
(In Pounds per Square Inch.)

Aggregate	1:1:2	1:1½:3	1:2:4	1:2½:5	1:3:6
Granite, trap rock	3300	2800	2200	1800	1400
Gravel, hard limestone and hard sandstone	3000	2500	2000	1600	1300
Soft limestone and sandstone	2200	1800	1500	1200	1000
Cinders	800	700	600	500	400

NOTE.—For variations in the moduli of elasticity see Chapter VIII, Section 8.

2. BEARING.

When compression is applied to a surface of concrete of at least twice the loaded area, a stress of 32.5 per cent of the compressive strength may be allowed.

3. AXIAL COMPRESSION.

For concentric compression on a plain concrete column or pier, the length of which does not exceed 12 diameters, 22.5 per cent of the compressive strength may be allowed.

For other forms of columns the stresses obtained from the ratios given in Chapter VII, Section 9, may govern.

4. COMPRESSION IN EXTREME FIBER.

The extreme fiber stress of a beam, calculated on the assumption of a constant modulus of elasticity for concrete under working stresses may be allowed to reach 32.5 per cent of the compressive strength. Adjacent to the support of continuous beams stresses 15 per cent higher may be used.

5. SHEAR AND DIAGONAL TENSION.

In calculations on beams in which the maximum shearing stress in a section is used as the means of measuring the resistance to diagonal tension stress, the following allowable values for the maximum vertical shearing stress are recommended:

(*a*) For beams with horizontal bars only and without web reinforcement calculated by the method given in the Appendix, Formula (22), 2 per cent of the compressive strength.

(*b*) For beams thoroughly reinforced with web reinforcement, the value of the shearing stress calculated as for (*a*) (that is, using the total external vertical shear in the Formula (22) for shearing unit stress) must not exceed 6 per cent of the compressive strength. The web reinforcement, exclusive of bent-up bars, in this case shall be proportioned to resist two-thirds of the external vertical shear in the formulas given in the Appendix, Formula (24) or (25).

(*c*) For beams in which part of the longitudinal reinforcement is used in the form of bent-up bars distributed over a portion of the beam in a way covering the requirements for this type of web reinforcement, the limit of maximum vertical shearing stress (the stress calculated as for (*a*)), 3 per cent of the compressive strength.

(*d*) Where punching shear occurs, that is, shearing stress uncombined with compression normal to the shearing surface, and with all tension normal to the shearing plane provided for by reinforcement, a shearing stress of 6 per cent of the compressive strength may be allowed.

6. BOND.

The bond stress between concrete and plain reinforcing bars may be assumed at 4 per cent of the compressive strength, or 2 per cent in the case of drawn wire.

7. REINFORCEMENT.

The tensile or compressive stress in steel should not exceed 16,000 lb. per sq. in.

In structural steel members the working stresses adopted by the American Railway Engineering Association are recommended.

8. MODULUS OF ELASTICITY.

The value of the modulus of elasticity of concrete has a wide range, depending on the materials used, the age, the range of stresses between which it is considered, as well as other conditions. It is recommended that in computations for the position of the neutral axis and for the resisting moment of beams and for compression of concrete in columns it be assumed as:

(*a*) One-fifteenth that of steel, when the strength of the concrete is taken as 2200 lb. per sq. in. or less.

(*b*) One-twelfth that of steel, when the strength of the concrete is taken as greater than 2200 lb. per sq. in. or less than 2900 lb. per sq. in., and

(*c*) One-tenth that of steel, when the strength of the concrete is taken as greater than 2900 lb. per sq. in.

Although not rigorously accurate, these assumptions will give safe results. For the deflection of beams which are free to move longitudinally at the supports, in using formulas for deflection which do not take into account the tensile strength developed in the concrete, a modulus of one-eighth of that of steel is recommended.

Respectfully submitted,

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IX. Appendix.

I. STANDARD SPECIFICATIONS.

(*a*) *Cement.*[1]

(*b*) *Metal Reinforcement.*[2]

6. Steel shall be made by the open-hearth process. Rerolled material will not be accepted.

7. Plates and shapes used for reinforcement shall be of structural steel only. Bars and wire may be structural steel or high-carbon steel.

8. The chemical and physical properties shall conform to the following limits:

Elements Considered.	Structural Steel.	High-Carbon Steel.
Phosphorus, maximum. Basic	0.04 per cent.	0.04 per cent.
Phosphorus, maximum. Acid	0.06 "	0.06 "
Sulphur, maximum	0.05 "	0.05 "
Ultimate tensile strength.	Desired	Desired
Pounds per square inch	60,000	88,000
	1,500,000*	1,000,000
Elong. min. per cent. in 8 ins., Fig. 1	Ult. tensile strength	Ult. tensile strength
Character of Fracture	Silky	Silky or finely granular
Cold Bends without Fracture	180° flat†	180° d=4t‡

* See Paragraph 15. † See Paragraphs 16 and 17. ‡ "d=4t" signifies "around a pin whose diameter is four times the thickness of the specimen."

9. The yield point for bars and wire, as indicated by the drop of the beam, shall be not less than 60 per cent of the ultimate tensile strength.

10. If the ultimate strength varies more than 4000 lb. for structural steel or 6000 lb. for high-carbon steel, a retest shall be made on the same gage, which, to be acceptable, shall be within 5000 lb. for structural steel, or 8000 lb. for high-carbon steel, of the desired ultimate.

11. Chemical determinations of the percentages of carbon,

[1] Adopted August 16, 1909, by the American Society for Testing Materials. See Year-Book for 1913, pp. 254–258.

[2] Adopted March 16, 1910, by the American Railway Engineering Association.

phosphorus, sulphur and manganese shall be made by the manufacturer from a test ingot taken at the time of the pouring of each melt of steel, and a correct copy of such analysis shall be furnished to the engineer or his inspector. Check analyses shall be made from finished material, if called for, in which case an excess of 25 per cent above the required limit will be allowed.

12. *Plates, Shapes and Bars.*—Specimens for tensile and bending tests for plates and shapes shall be made by cutting coupons from the finished product, which shall have both faces rolled and both edges milled to the form shown by Fig. 1; or with both edges parallel; or they may be turned to a diameter of $\frac{3}{4}$ in. with enlarged ends.

13. Bars shall be tested in their finished form.

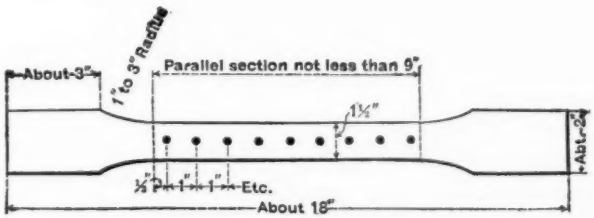


FIG. 1.—TEST PIECE FOR TENSION TEST.

14. At least one tensile and one bending test shall be made from each melt of steel as rolled. In case steel differing $\frac{3}{8}$-in. and more in thickness is rolled from one melt, a test shall be made from the thickest and thinnest material rolled.

15. For material less than $\frac{5}{16}$ in. and more than $\frac{3}{4}$ in. in thickness, the following modifications will be allowed in the requirements for elongation:

(*a*) For each $\frac{1}{16}$ in. in thickness below $\frac{5}{16}$ in. a deduction of 2.5 will be allowed from the specified percentage.

(*b*) For each $\frac{1}{8}$ in. in thickness above $\frac{3}{4}$ in., a deduction of 1 will be allowed from the specified percentage.

16. Bending tests may be made by pressure or by blows. Shapes and bars less than 1 in. thick shall bend as called for in Paragraph 8.

17. Test specimens 1 in. thick and over shall bend cold

180 deg. around a pin, the diameter of which, for structural steel, is twice the thickness of the specimen, and for high-carbon steel, is six times the thickness of the specimen, without fracture on the outside of the bend.

18. Finished material shall be free from injurious seams, flaws, cracks, defective edges or other defects, and have a smooth, uniform and workmanlike finish.

19. Every finished piece of steel shall have the melt number and the name of the manufacturer stamped or rolled upon it, except that bar steel and other small parts may be bundled with the above marks on an attached metal tag.

20. Material which, subsequent to the above tests at the mills and its acceptance there, develops weak spots, brittleness, cracks or other imperfections, or is found to have injurious defects, will be rejected and shall be replaced by the manufacturer at his own cost.

21. All reinforcing steel shall be free from excessive rust, loose scale, or other coatings of any character which would reduce or destroy the bond.

2. SUGGESTED FORMULAS FOR REINFORCED CONCRETE CONSTRUCTION.

These formulas are based on the assumptions and principles given in the chapter on design.

(*a*) *Standard Notation.*

1. *Rectangular Beams.*

The following notation is recommended:

f_s = tensile unit stress in steel.
f_c = compressive unit stress in concrete.
E_s = modulus of elasticity of steel.
E_c = modulus of elasticity of concrete.
$n = \frac{E_s}{E_c}$
M = moment of resistance, or bending moment in general.
A = steel area.

b = breadth of beam.
d = depth of beam to center of steel.
k = ratio of depth of neutral axis to effective depth d.
z = depth of resultant compression below top.
j = ratio of lever arm of resisting couple to depth d.
$jd = d - z$ = arm of resisting couple.
p = steel ratio (not percentage).

2. *T-Beams.*

b = width of flange.
b' = width of stem.
t = thickness of flange.

3. *Beams Reinforced for Compression.*

A' = area of compressive steel.
p' = steel ratio for compressive steel.
f_s' = compressive unit stress in steel.
C = total compressive stress in concrete.
C' = total compressive stress in steel.
d' = depth to center of compressive steel.
z = depth to resultant of C and C'.

4. *Shear and Bond.*

V = total shear.
v = shearing unit stress.
u = bond stress per unit area of bar.
o = circumference or perimeter of bar.
Σo = sum of the perimeters of all bars.

5. *Columns.*

A = total net area.
A_s = area of longitudinal steel.
A_c = area of concrete.
P = total safe load.

(b) Formulas.

1. *Rectangular Beams.*

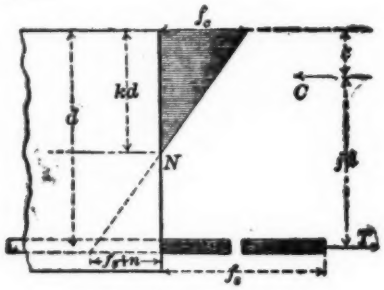


FIG. 2.

Position of neutral axis,

$$k = \sqrt{2pn + (pn)^2} - pn. \tag{1}$$

Arm of resisting couple,

$$j = 1 - \frac{1}{3}k. \tag{2}$$

[For $f_s = 15000$ to 16000 and $f_c = 600$ to 650, k may be taken at $\frac{7}{8}$.]

Fiber stresses,

$$f_s = \frac{M}{Ajd} = \frac{M}{pjbd^2}. \tag{3}$$

$$f_c = \frac{2M}{jkbd^2} = \frac{2pf_s}{jk}. \tag{4}$$

Steel ratio, for balanced reinforcement,

$$p = \frac{1}{2} \cdot \frac{1}{\frac{f_s}{f_c}\left(\frac{f_s}{nf_c} + 1\right)}. \tag{5}$$

2. *T-Beams.*

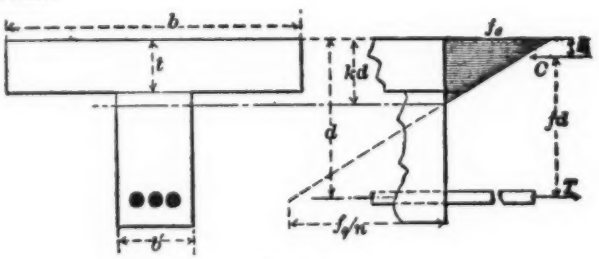


FIG. 3.

Case I. When the neutral axis lies in the flange, use the formulas for rectangular beams.

Case II. When the neutral axis lies in the stem.

The following formulas neglect the compression in the stem. Position of neutral axis,

$$kd = \frac{2ndA + bt^2}{2nA + 2bt}. \tag{6}$$

Position of resultant compression,

$$z = \frac{3kd - 2t}{2kd - t} \cdot \frac{t}{3}. \tag{7}$$

Arm of resisting couple,

$$jd = d - z. \tag{8}$$

Fiber stresses,

$$f_s = \frac{M}{Ajd}. \tag{9}$$

$$f_c = \frac{Mkd}{bt(kd - \frac{1}{2}t)jd} = \frac{f_s}{n} \cdot \frac{k}{1-k}. \tag{10}$$

(For approximate results the formulas for rectangular beams may be used.)

The following formulas take into account the compression in the stem; they are recommended where the flange is small compared with the stem:

Position of neutral axis,

$$kd = \sqrt{\frac{2ndA + (b-b')t^2}{b'} + \left(\frac{nA + (b-b')t}{b'}\right)^2} - \frac{nA + (b-b')t}{b'}. \tag{11}$$

Position of resultant compression,

$$z = \frac{(kdt^2 - \frac{2}{3}t^3)b + [(kd-t)^2(t + \frac{1}{3}(kd-t))]b'}{t(2kd-t)b + (kd-t)^2b'}. \tag{12}$$

Arm of resisting couple,

$$jd = d - z. \tag{13}$$

Fiber stresses,

$$f_s = \frac{M}{Ajd}. \tag{14}$$

$$f_c = \frac{2Mkd}{[(2kd-t)bt + (kd-t)^2b']jd}. \tag{15}$$

3. *Beams Reinforced for Compression.*

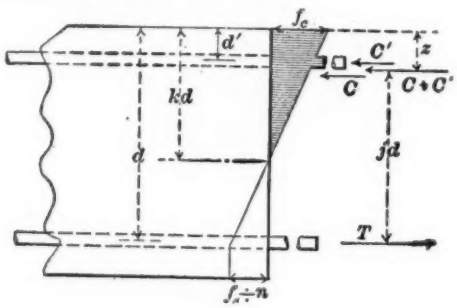


FIG. 4.

Position of neutral axis,

$$k = \sqrt{2n\left(p+p'\frac{d'}{d}\right)+n^2(p+p')^2} - n(p+p'). \tag{16}$$

Position of resultant compression,

$$z = \frac{\frac{1}{3}k^3d + 2p'nd'\left(k-\frac{d'}{d}\right)}{k^2+2p'n\left(k-\frac{d'}{d}\right)}. \tag{17}$$

Arm of resisting couple,

$$jd = d - z. \tag{18}$$

Fiber stresses,

$$f_c = \frac{6M}{bd^2\left[3k-k^2+\frac{6p'n}{k}\left(k-\frac{d'}{d}\right)\left(1-\frac{d'}{d}\right)\right]}. \tag{19}$$

$$f_s = \frac{M}{pjbd^2} = nf_c\frac{1-k}{k}. \tag{20}$$

$$f_s' = nf_c\frac{k-\frac{d'}{d}}{k}. \tag{21}$$

4. *Shear, Bond and Web Reinforcement.*

In the following formulas Σo refers only to the bars constituting the tension reinforcement at the section in question and jd is the lever arm of the resisting couple at the section.

For rectangular beams,

$$v = \frac{V}{bjd}. \tag{22}$$

$$u = \frac{V}{jd \cdot \Sigma o}. \tag{23}$$

[For approximate results j may be taken at $\frac{7}{8}$.]

The stresses in web reinforcement may be estimated by means of the following formulas:

Vertical web reinforcement,

$$P = \frac{Vs}{jd}. \tag{24}$$

Web reinforcement inclined at 45° (not bent-up bars).

$$P = 0.7\,\frac{Vs}{jd}, \tag{25}$$

in which P = stress in single reinforcing member, V = amount of total shear assumed as carried by the reinforcement, and s = horizontal spacing of the reinforcing members.

The same formulas apply to beams reinforced for compression as regards shear and bond stress for tensile steel.

For T-Beams,

$$v = \frac{V}{b'jd}. \tag{26}$$

$$u = \frac{V}{jd \cdot \Sigma o}. \tag{27}$$

[For approximate results j may be taken at $\frac{7}{8}$.]

5. *Columns.*

Total safe load,

$$P = f_c(A_c + nA_s) = f_c A(1 + (n-1)p). \tag{28}$$

Unit stresses,

$$f_c = \frac{P}{A(1 + (n-1)p)}. \tag{29}$$

$$f_s = nf_c. \tag{30}$$

REPORT OF COMMITTEE C-3

ON

STANDARD SPECIFICATIONS FOR BRICK.

At the twelfth annual meeting of the Society in 1909 this committee, designated at that time as Committee D, submitted a report including some suggested specifications which were offered for use but not intended, at the time, for adoption. The lack of accurate knowledge regarding the properties of brick, the methods of testing them, the relations existing between the properties which could be measured and their influence in the finished structure, compelled the committee to refrain from any definite recommendations. This condition has continued during the succeeding years and little progress has been made. In 1911 the committee was considerably enlarged and organized into two sub-committees, one on building brick, the other on paving brick. A program outlining a series of investigations was formulated and has, through the cooperation of some of the manufacturers and testing laboratories, progressed sufficiently to yield some reliable results. It is hoped that during the coming year a greater number of laboratories may become interested and assist in the collection of much needed data.

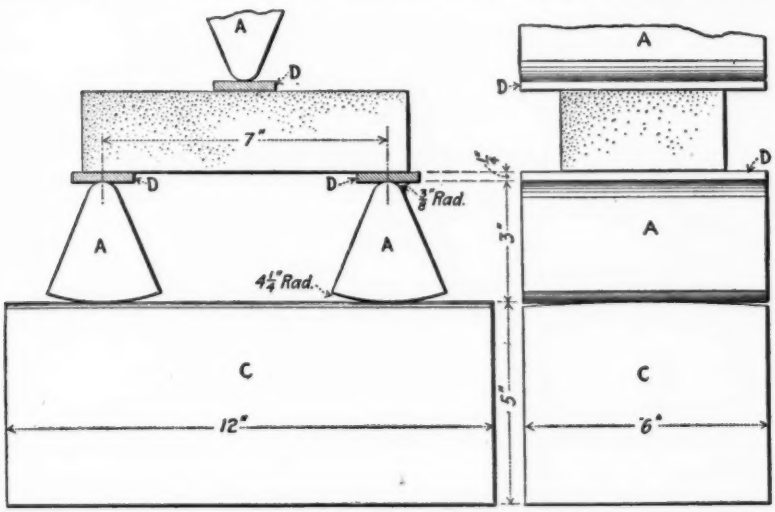
The University engineering laboratories and the laboratories of large companies have during the past twenty years devoted a large amount of energy and money to the investigation of steel and steel products; the new and attractive alloys; cement and cement products; and built-up members involving these materials in their construction. Comparatively little attention has been paid to structural clay products.

Brick, the most extensively used structural material in the country, and ceramic materials such as hollow tile, terra cotta, fireproofing and the mortars used with them, form one of the most fertile fields for engineering investigation.

BUILDING BRICK.

In the preparation of the appended proposed standard specifications for Building Brick, the committee has felt that its chief aim should be to provide methods for contractual testing rather than for the purposes of investigations.

The numerical requirements included in the suggested specifications are therefore limited to those properties upon which the committee has at the present time sufficient information to enable it to indicate reasonable values. The trans-



A = Cast-Iron Wedges, C = Soft Wood Block, D = Cold-Rolled Steel Plates.

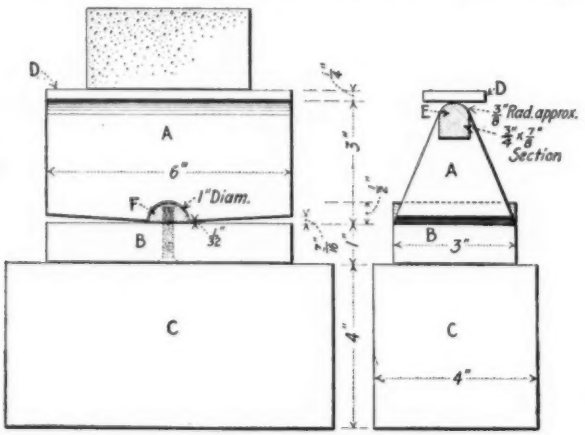
FIG. 1.

verse test and the numerical values for the compressive strength after freezing and thawing have been omitted for the lack of sufficient data. The committee recognizes the value of these tests and expects to obtain information on them during the next year.

As a comparative test between different kinds of brick, the transverse test may be considered as a modified tension test to determine the cohesion of the materials and to form a valuable estimate of their relative resistance to transverse action in a structure when subject to uneven bearing, settling and

temperature changes. It also assists in the determination of the effect of various kinds of lamination. For the purpose of making comparative tests and for the proposed investigations of the committee, the following methods are suggested:

Transverse Test.—At least five bricks shall be tested, laid flatwise with a span of 7 in., and with the load applied at mid-span. The knife edges shall be slightly curved in the direction of their length. Steel bearing plates, about $\frac{1}{4}$ in. thick by $1\frac{1}{2}$ in. wide may be placed between the knife edges and the brick. The use of a wooden base block, slightly rounded transversely



A, B = Cast-Iron Wedges; C = Soft Wood Block; D, E, F = Cold-Rolled Steel.

FIG. 2

across its top, upon which to rest the lower knife edges (see Fig. 1), or the form of lower knife edge shown in Fig. 2, is recommended. If the knife edges shown in Fig. 2 are used, they should rest upon smooth plane blocks of wood at least 2 in. thick. The modulus of rupture shall be obtained by the following formula:

$$R = \frac{3We}{2bd^2}$$

in which e is the distance between supports in inches, b is the breadth and d the depth of the brick in inches, and W is the load in pounds at which the brick failed.

There can be no question of the far-reaching value of the freezing test, since information of this nature referring to all of stone-like building materials is urgently needed.

If the freezing test is desired the committee suggests the following method:

Freezing Test.—At least five bricks shall be dried as specified under "Sampling" below, weighed, and immersed in water which shall be raised to boiling in not less than 30 minutes, boiled for 30 minutes, and allowed to cool to between 60° and 80° F. The specimens shall be immersed in water below 40° F. for not less than one hour, then transferred to the refrigerator and supported in such a manner that all sides are exposed. They shall be subjected to a temperature not above 20° F. for at least 4 hours, then removed and placed in water at a temperature between 60° and 80° F. and raised to boiling. The freezing and thawing operation shall be repeated twenty times, after which the bricks shall be dried as before and weighed. The condition of the bricks shall be noted before and during the test and all visible changes recorded. If it is desired to express the loss of weight in percentage, it shall be computed upon the dry weight.

Classification.—In attempting to establish values in the "Requirements," the committee has been confronted with the difficulty of not only having to meet the numerous uses of brick, but the wide divergence in various parts of the country on account of the different natural materials available for manufacture. The difficulty has been overcome by forming a classification which it is believed will meet these conditions.

PAVING BRICK.

Proposed Standard Specifications for Paving Brick have been drawn up by the Sub-Committee on Paving Brick, under the chairmanship of Mr. Edward Orton, Jr., and are appended to this report.

A. V. BLEININGER,
Chairman.

D. E. DOUTY,
Secretary.

AMERICAN SOCIETY FOR TESTING MATERIALS

PHILADELPHIA, PA., U. S. A.

AFFILIATED WITH THE

INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

PROPOSED STANDARD SPECIFICATIONS

FOR

BUILDING BRICK.

Sampling.—For the purpose of tests, brick shall be selected to represent the commercial product by an experienced person agreed upon by the parties to the contract. All brick shall be carefully examined and their condition noted before being subjected to any kind of test.

For the purpose of the tests ten bricks will be required, which shall be thoroughly dried to constant weight in a suitable oven at a temperature of from 225° F. (107° C.) to 250° F. (121° C.).

Compression Test.—Compression tests shall be made on at least five half-bricks each taken from a different brick. The half-brick shall be prepared either by sawing or by breaking upon a yielding bed with a sharp mason's chisel which shall be the full width of the brick. To secure a uniform bearing in the testing machine they shall be bedded in a thin coat of plaster of Paris, spread upon a plate glass surface coated with a thin layer of oil. The brick shall be pressed firmly upon the surface, making the layer as thin as possible, and remain undisturbed until set. Before applying the plaster of Paris, the bearing surface of the brick shall receive a coat of shellac.

Recessed or paneled brick should be brought to full bear-

ing surface by filling the depression with neat Portland cement mortar, which shall stand at least 24 hours before the plaster of Paris is applied.

The machine used for the compression test shall be equipped with a spherical bearing block kept thoroughly lubricated to insure accurate adjustment, and the adjustment should be made by hand under a small initial load. During the test the beam of the testing machine shall be kept constantly in a floating position. The breaking load shall be divided by the area in compression and the results reported in pounds per square inch.

Absorption.—At least five dry bricks shall be weighed and completely submerged in water at a temperature between 60° and 80° F., the water heated to boiling within one hour, boiled continuously for 4 hours, then allowed to cool in the water to a temperature between 60° and 80° F.

They should then be removed, the surface water wiped off with a cloth and the brick quickly weighed. The percentage of absorption shall be computed on the dry weight.

REQUIREMENTS.

Class A.—Vitrified Brick.

Average compressive strength	not less than	5000 lb. per sq. in.
Minimum compressive strength, of any specimen in test	not less than	4500 " "
Average absorption	not more than	5 per cent

Class B.—Hard-Burned Brick.

Average compressive strength	not less than	3500 lb. per sq. in.
Minimum compressive strength of any specimen in the test	not less than	3000 " "
Average absorption	not more than	12 per cent

If subjected to the freezing test, they shall not show cracking or serious spalling in any of the bricks tested or serious disintegration of the material.

Class C.—Common Brick, First.

Average compressive strength	not less than	2000 lb. per sq. in.
Minimum compressive strength of any specimen in the test	not less than	1800 " "
Average absorption	not more than	18 per cent

If subjected to the freezing test, they shall not show cracking or serious spalling in any of the bricks tested or serious disintegration of the material.

Class D.—Common Brick, Second.

(These bricks to be used only for backing-up and for interior walls involving small loads.)

Average compressive strength	not less than	1500 lb. per sq. in
Minimum compressive strength of any specimen in the test	not less than	1200 " "

Miscellaneous.

Any brick other than clay brick may be included in Classes A, B and C, provided they meet the specified requirements; and when the freezing test is required, it shall not show cracking or serious spalling in any of the bricks tested or serious disintegration of the material.

AMERICAN SOCIETY FOR TESTING MATERIALS

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AFFILIATED WITH THE

INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

PROPOSED STANDARD SPECIFICATIONS FOR PAVING BRICK.

The quality and acceptability of paving brick, in the absence of other special tests mutually agreed upon in advance by the seller on the one side and the buyer on the other side, shall be determined by the following procedure:

I. *The Rattler Test*, for the purpose of determining whether the material as a whole possesses to a sufficient degree strength, toughness and hardness.

II. *Visual Inspection*, for the purpose of determining whether the physical properties of the material as to dimensions, accuracy and uniformity of shape and color, are in general satisfactory, and for the purpose of culling out from the shipment individually imperfect or unsatisfactory brick.

The acceptance of paving brick as satisfactorily meeting one of these tests shall not be construed as in any way waiving the other.

I. THE RATTLER TEST.

THE SELECTION OF SAMPLES FOR TEST.

1. *Place of Sampling.*—In general, where a shipment of bricks involving a quantity of less than 100,000 is under consideration, the sampling may be done either at the brick factory

prior to shipment, or on cars at their destination or on the street, when delivered ready for use. When the quantity under consideration exceeds 100,000 the sampling shall be done at the factory prior to shipment. Bricks accepted as the result of test prior to shipment, shall not be liable to subsequent rejection as a whole, but are subject to such culling as is provided for under Part II, Visual Inspection.

2. *Method of Selecting Samples.*—In general, the buyer shall select his own samples from the material which the seller proposes to furnish. The seller shall have the right to be present during the selection of a sample. The sampler shall endeavor, to the best of his judgment, to select brick representing the average of the lot. No samples shall include bricks which would be rejected by visual inspection as provided in Part II, except that where controversy arises, whole tests may be selected to determine the admissibility of certain types or portions of the lot having a characteristic appearance in common. In cases where prolonged controversy occurs between buyer and seller and samples selected by each party fail to show reasonable concurrence, then both parties shall unite in the selection of a disinterested person to select the samples, and both parties shall be bound by the results of samples thus selected.

3. *Number of Samples per Lot.*—In general, one sample of ten bricks shall be tested for every 10,000 bricks contained in the lot under consideration; but where the total quantity exceeds 100,000, the number of samples tested may be fewer than one per 10,000, provided that they shall be distributed as uniformly as practicable over the entire lot.

4. *Shipment of Samples.*—Samples which must be transported long distances by freight or express shall be carefully put up in packages holding not more than twelve bricks each. When more than six bricks are shipped in one package, it shall be so arranged as to carry two parallel rows of bricks side by side, and these rows shall be separated by a partition. In event of some of the bricks being cracked or broken in transit, the sample shall be disqualified if there are not remaining ten sound undamaged bricks.

5. *Storage and Care of Samples.*—Samples shall be carefully handled to avoid breakage or injury. They shall be

kept in the dry so far as practicable. If wet when received, or known to have been immersed or subjected to recent prolonged wetting, they shall be dried for at least six hours in a temperature of 100° F. before testing.

THE CONSTRUCTION OF THE RATTLER.

6. *General Design.*—The machine shall be of good mechanical construction, self-contained, and shall conform to the following details of material and dimensions, and shall consist of barrel, frame, and driving mechanism as herein described. Accompanying these specifications is a complete drawing of a rattler which will meet the requirements, and to which reference should be made (Plate VII).[1]

7. *The Barrel.*—The barrel of the machine shall be made up of the heads, headliners, staves and stave-liners.

The heads may be cast in one piece with the trunnions, which shall be $2\frac{1}{2}$ in. in diameter, and shall have a bearing 6 in. in length, or they may be cast with heavy hubs, which shall be bored out for $2\frac{7}{16}$-in. shafts, and shall be keyseated for two keys, each $\frac{1}{2}$ by $\frac{3}{8}$ in. and spaced 90 deg. apart. The shaft shall be a snug fit and when keyed shall be entirely free from lost motion. The distance from the end of the shaft or trunnion to the inside face of the head shall be $15\frac{3}{8}$ in. in the head for the driving end of the rattler, and $11\frac{3}{8}$ in. for the other head, and the distance from the face of the hubs to the inside face of the heads shall be $5\frac{1}{8}$ in.

The heads shall be not less than $\frac{3}{4}$ in. thick, nor more than $\frac{7}{8}$ in. thick. In outline, each head shall be a regular 14-sided polygon inscribed in a circle $28\frac{3}{8}$ in. in diameter. Each head shall be provided with flanges not less than $\frac{3}{4}$ in. thick and extending outward $2\frac{1}{2}$ in. from the inside face of the head to afford a means of fastening the staves. The surface of the flanges of the head shall be smooth and give a true and uniform bearing for the staves. To secure the desired true and uniform bearing the surfaces of the flanges of the head shall be either ground or machined. The flanges shall be slotted on the outer edge, so as to provide for two $\frac{3}{4}$-in. bolts at each end of each stave,

[1] This rattler was designed jointly by Mr. M. W. Blair and Mr. C. F. Hetherington.

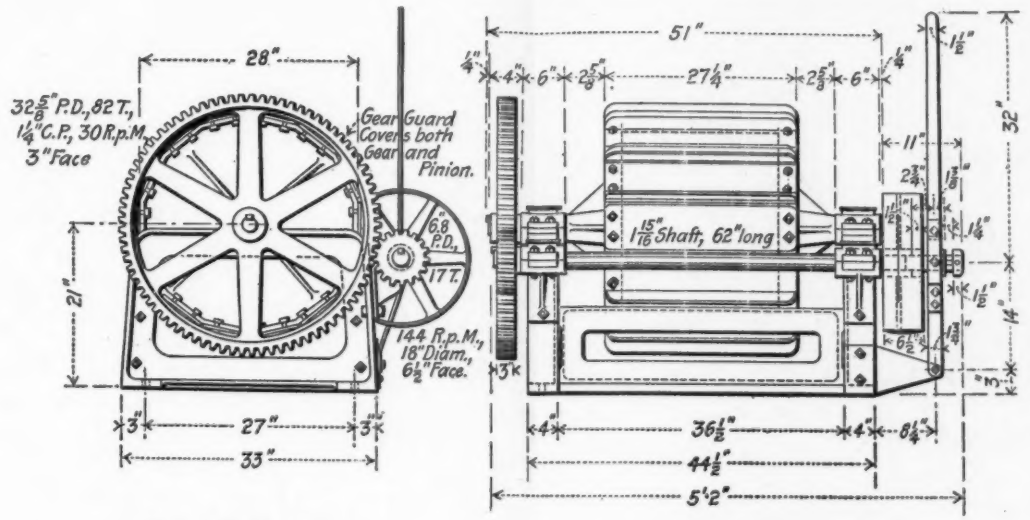
said slots to be $\frac{13}{16}$ in. wide and $2\frac{3}{4}$ in., center to center. Each slot shall be provided with a recess for the bolt head, which shall act to prevent the turning of the same. Between each two slots there shall be a brace $\frac{3}{8}$ in. thick, extending down the outward side of the head not less than 2 in.

There shall be for each head a cast-iron headliner 1 in. in thickness and conforming to the outline of the head, but inscribed in a circle $28\frac{1}{8}$ in. in diameter. This headliner shall be fastened to the head by seven $\frac{5}{8}$-in. cap-screws, through the head from the outside. Whenever these headliners become worn down $\frac{1}{2}$ in. below their initial surface level at any point of their surface, they shall be replaced with new ones. The metal of these headliners shall be hard machinery iron and should contain not less than one per cent of combined carbon.

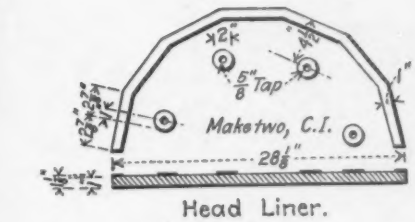
The staves shall be made of 6-in. medium-steel structural channels, $27\frac{1}{4}$ in. long and weighing 15.5 lb. per lineal foot. The staves shall have two holes $\frac{13}{16}$ in. in diameter, drilled in each end, the center line of the holes being 1 in. from the end and $1\frac{3}{8}$ in. either way from the longitudinal center line. The spaces between the staves shall be as uniform as practicable, but shall not exceed $\frac{5}{16}$ in.

The interior or flat side of each stave shall be protected by a liner $\frac{3}{8}$ in. thick by $5\frac{1}{2}$ in. wide by $19\frac{3}{4}$ in. long. The liner shall consist of medium-steel plate, and shall be riveted to the channel by three $\frac{1}{2}$-in. rivets, one of which shall be on the center line both ways and the other two on the longitudinal center line and spaced 7 in. from the center each way. The rivet holes shall be countersunk on the face of the liner and the rivets shall be driven hot and chipped off flush with the surface of the liners. These liners shall be inspected from time to time, and if found loose shall be at once re-riveted; but no liner shall be replaced by a new one except as the whole set is changed.

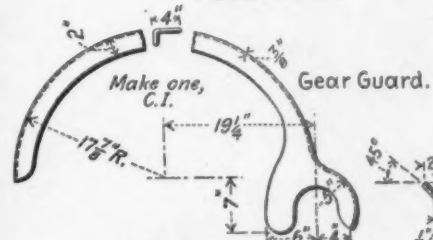
Any test at the expiration of which a stave-liner is found detached from the stave or seriously out of position shall be rejected. When a new set of liners has been placed in position, before being used for testing, the rattler shall be charged with 400 lb. of shot of the same sizes, and in the same proportions as provided in Section 9, and shall then be run for 18,000 revolutions at the usual prescribed rate of speed. The shot shall

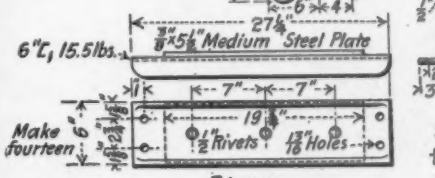


End Elevation. Side Elevation.

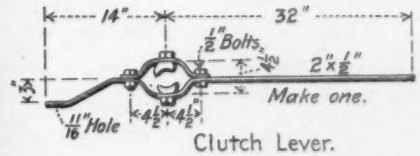


Head Liner.

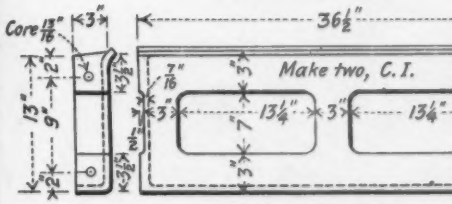




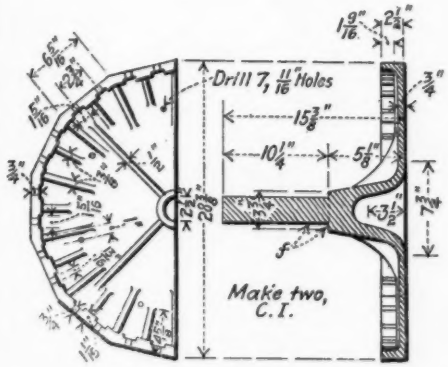
Stave.



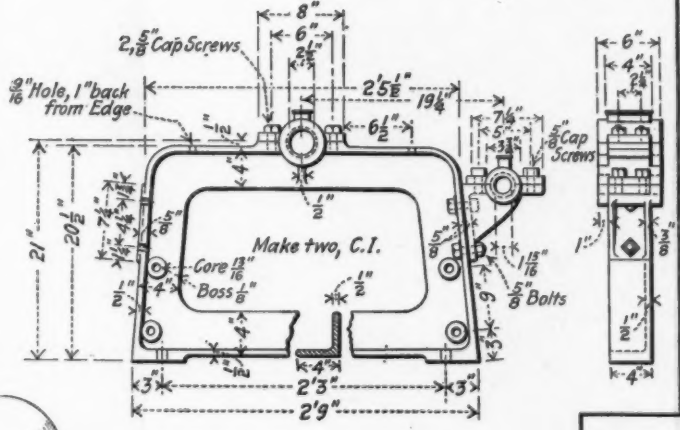
Clutch Lever.



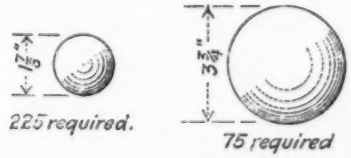
Side Frame.



Trunnion.



End Frame.



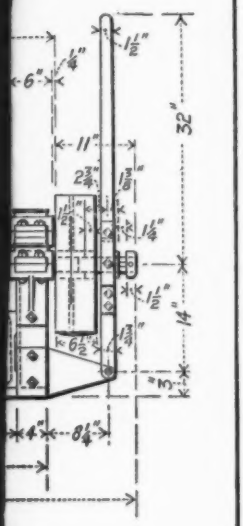
Spherical Shot.

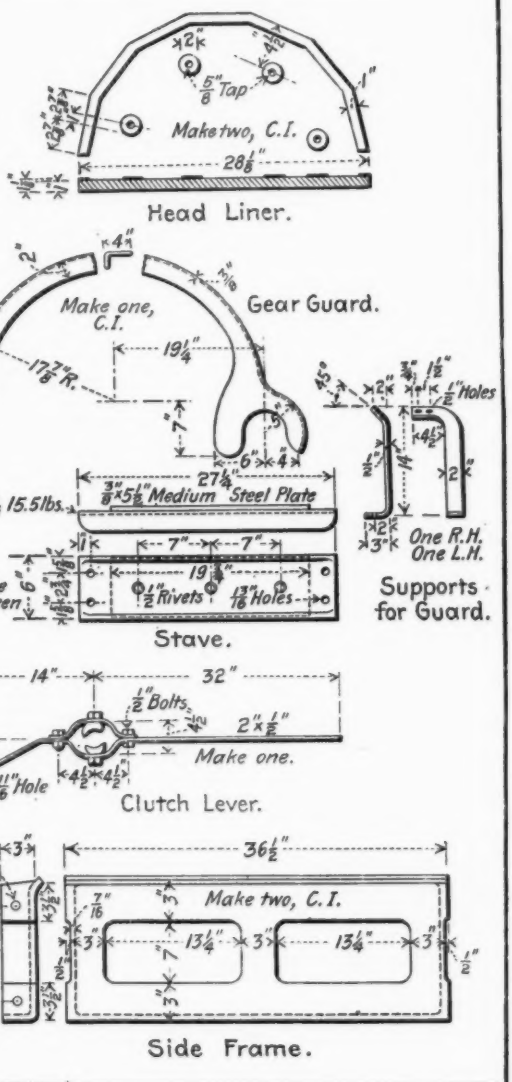
STANDARD RATTLER FOR TESTING PAVING BRIC

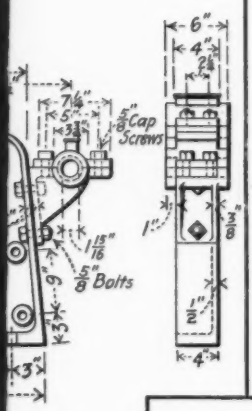
PROPOSED BY

THE NATIONAL PAVING BRICK MANUFACTURERS' ASSOCIAT

December 1, 1910







STANDARD RATTLER
FOR
TESTING PAVING BRICK

PROPOSED BY

THE NATIONAL PAVING BRICK MANUFACTURERS' ASSOCIATION

December 1, 1910

then be removed and a standard shot charge inserted, after which the rattler may be charged with brick for a test.

No set of liners shall be used for more than one hundred tests. The record must show the date when each set of liners goes into service, and the number of tests made upon each set.

The staves when bolted to the heads shall form a barrel 20 in. long, inside measurement, between head liners. The liners of the staves shall be so placed as to drop between the head-liners. The staves shall be bolted tightly to the heads by four $\frac{3}{4}$-in. bolts, and each bolt shall be provided with a lock nut, and shall be inspected at not less frequent intervals than every fifth test and all nuts kept tight. A record shall be made after each inspection showing in what condition the bolts were found.

8. *The Frame and Driving Mechanism.*—The barrel shall be mounted on a cast-iron frame of sufficient strength and rigidity to support it without undue vibration. It shall rest on a rigid foundation with or without the interposition of wooden plates, and shall be fastened thereto by bolts at not less than four points.

It shall be driven by gearing whose ratio of driver to driven is not less than one to four. The counter shaft upon which the driving pinion is mounted shall not be less than $1\frac{15}{16}$ in. in diameter, with bearings not less than 6 in. in length. It shall be belt driven, and the pulley shall not be less than 18 in. in diameter and $6\frac{1}{2}$ in. in face. A belt of 6-in. double-strength leather, properly adjusted, to avoid unnecessary slipping, should be used.

9. *The Abrasive Charge.*—The abrasive charge shall consist of cast-iron spheres of two sizes. When new, the larger spheres shall be 3.75 in. in diameter and shall weigh approximately 7.5 lb. (3.40 kg.) each. Ten spheres of this size shall be used.

These shall be weighed separately after each ten tests, and if the weight of any large sphere falls to 7 lb. (3.175 kg.) it shall be discarded and a new one substituted; provided, however, that all of the large spheres shall not be discarded and substituted by new ones at any single time, and that so far as possible the large spheres shall compose a graduated series in various stages of wear.

When new, the smaller spheres shall be 1.875 in. in diameter and shall weigh approximately 0.95 lb. (0.43 kg.) each. In general, the number of small spheres in a charge shall not fall below 245 nor exceed 260. The collective weight of the large and small spheres shall be as nearly 300 lb. as possible. No small sphere shall be retained in use after it has been worn down so that it will pass a circular hole 1.75 in. in diameter, drilled in an iron plate $\frac{1}{4}$ in. in thickness, or weigh less than 0.75 lb. (0.34 kg.). Further, the small spheres shall be tested, by passing them over the above plate or by weighing, after every ten tests, and any which pass through or fall below the specified weight, shall be replaced by new spheres; provided, further, that all of the small spheres shall not be rejected and replaced by new ones at any one time, and that so far as possible the small spheres shall compose a graduated series in various stages of wear. At any time that any sphere is found to be broken or defective it shall at once be replaced.

The iron composing these spheres shall have a chemical composition within the following limits:

Combined carbon	Not under	2.50	per cent
Graphitic carbon	" over	0.25	"
Silicon	" "	1.00	"
Manganese	" "	0.50	"
Phosphorus	" "	0.25	"
Sulphur	" "	0.08	"

For each new batch of spheres used, the chemical analysis shall be furnished by the maker or be obtained by the user, before introducing into the charge, and unless the analysis meets the above specifications, the batch of spheres shall be rejected.

THE OPERATION OF THE TEST.

10. *The Brick Charge.*—The number of bricks per test shall be ten for all bricks of so-called "block size," whose dimensions fall between from 8 and 9 in. in length, 3 and $3\frac{3}{4}$ in. in breadth, and $3\frac{3}{4}$ and $4\frac{1}{4}$ in. in thickness.[1] No brick should

[1] Where brick of larger or smaller sizes than the dimensions given above for blocks are to be tested, the same number of bricks per charge should be used, but allowance for the difference in size should be made in setting the limits for average and maximum rattler loss.

be selected as part of a regular test that would be rejected by any other requirements of the specifications under which the purchase is made.

11. *Speed and Duration of Revolution.*—The rattler shall be rotated at a uniform rate of not less than 29.5 nor more than 30.5 revolutions per minute, and 1800 revolutions shall constitute the test. A counting machine shall be attached to the rattler for counting the revolutions. A margin of not to exceed ten revolutions will be allowed for stopping. Only one start and stop per test is generally acceptable. If, from accidental causes, the rattler is stopped and started more than once during a test, and the loss exceeds the maximum permissible under the specifications, the test shall be disqualified and another made.

12. *The Scales.*—The scales must have a capacity of not less than 300 lb., and must be sensitive to 0.5 oz., and must be tested by a standard test weight at intervals of not less than every ten tests.

13. *The Results.*—The loss shall be calculated in percentage of the initial weight of the brick composing the charge. In weighing the rattled brick, any piece weighing less than 1 lb. shall be rejected.

14. *The Recoras.*—A complete and continuous record shall be kept of the operation of all rattlers working under these specifications. This record shall contain the following data concerning each test made:

1. The name of the person, firm or corporation furnishing each sample tested.
2. The name of the maker of the brick represented in each sample tested.
3. The name of the street, or contract, which the sample represented.
4. The brands or marks upon the bricks by which they were identified.
5. The number of bricks furnished.
6. The date on which they were received for test.
7. The date on which they were tested.
8. The drying treatment given before testing, if any.
9. The length, breadth and thickness of the bricks.
10. The collective weight of the ten large spherical shot used in making the test at the time of their last standardization.
11. The number and collective weight of the small spherical shot used in making the test, at the time of their last standardization.
12. The total weight of the shot charge, after its last standardization.

13. Certificate of the operator that he examined the condition of the machine as to staves, liners, and any other parts affecting the barrel, and found them right at the beginning of the test.

14. Certificate of the operator of the number of charges tested since the last standardization of shot charge.

15. Certificate of the operator of the number of charges tested since the stave liners were renewed.

16. Certificate of the operator that the requisite number of revolutions were made, under the prescribed conditions, upon the staves after the last relining, before a brick test was made.

17. The time of the beginning and ending of each test, and the number of revolutions made by the barrel during the test, as shown by the indicator.

18. Certificate of the operator as to number of stops and starts made in each test.

19. The initial collective weight of the ten bricks composing the charge and their collective weight after rattling.

20. The loss calculated in percentage of the initial weight; and the calculation itself.

21. The number of broken bricks and remarks upon the portions which were included in the final weighing.

22 General remarks upon the test and any irregularities occurring in its execution.

23. The date upon which the test was made.

24. The location of the rattler and name of the owner, upon which the test was made.

25. The certificate of the operator that the test was made under the specifications of the American Society for Testing Materials and that the record is a true record.

26. The signature of the operator or person responsible for the test.

27. The serial number of the test.

In the event of more than one copy of the record of any test being required, they may be furnished on separate sheets, and marked duplicates, but the original record shall always be preserved intact and complete.

For the convenience of the public, the accompanying blank form, which provides space for the necessary data, is furnished and its use recommended.

ACCEPTANCE AND REJECTION OF MATERIAL.

15. *Basis of Acceptance or Rejection.*—Paving bricks shall not be judged for acceptance or rejection by the results of individual tests, but by the average of no less than five tests. Where a lot of bricks fail to meet the required average, it shall

Serial No.....

REPORT OF STANDARD RATTLER TEST OF PAVING BRICK.

IDENTIFICATION DATA.

Name of the firm furnishing sample.....
Name of the firm manufacturing sample.....
Street or job which sample represents.....
Brands or marks on the brick.....
Quantity furnished..... Drying treatment.....
Date received..... Date tested.....
Length..... Breadth..... Thickness.....

STANDARDIZATION DATA.

Weight of Charge. (After Standardization.)	Condition of Locknuts on Staves.	Condition of Scales.	Repairs. (Note any repairs affecting the condition of the barrel.)
10 Large spheres.....			
Small spheres.....			
Total.....			

Number of charges tested since last inspection.....
Number of charges tested since stave linings were renewed.....
Number of revolutions run upon stave linings before first test was run.....

RUNNING DATA.

	Time Readings.			Revolution Counter Readings.	Running Notes, Stops, etc.
	Hours.	Minutes.	Seconds.		
Beginning of Test..					
Final Reading.....					

WEIGHTS AND CALCULATIONS.

		Percentage Loss. (Note.—The Calculation Must Appear.)
Initial Weight of Ten Bricks.....		
Final Weight of Same.....		
Loss of Weight.....		

Number of broken bricks and remarks on same.....

I certify that the foregoing test was made under the specifications of the American Society for Testing Materials, and is a true record.

(Signature of Tester).....

Date.....

Location of Laboratory.....

be optional with the buyer whether the bricks shall be definitely rejected or whether they may be regraded and a portion selected for further test as provided in Section 16.

16. *Range of Fluctuation.*—Some fluctuation in the results of the rattler test, both on account of variations in the bricks and in the machine used in testing, are unavoidable, and a reasonable allowance for such fluctuations should be made, wherever the standard may be fixed.

In any lot of paving brick, if the loss on a test computed upon its initial weight exceeds the standard loss by more than two per cent, then the portion of the lot represented by that test shall at once be resampled and three more tests executed upon it, and if any of these three tests shall again exceed by more than two per cent the required standard, then that portion of the lot shall be rejected.

If in any lot of brick, two or more tests exceed the permissible maximum, then the buyer may at his option reject the entire lot, even though the average of all the tests executed may be within the required limits.

17. *Fixing of Standards.*—The percentage of loss which may be taken as the standard, will not be fixed in these regulations, and shall remain within the province of the contracting parties. For the information of the public, the following scale of average losses is given, representing what may be expected of tests executed under the foregoing specifications:

	GENERAL AVERAGE LOSS, PER CENT.	MAXIMUM PERMISSIBLE LOSS, PER CENT.
For bricks suitable for heavy traffic	22	24
For bricks suitable for medium traffic	24	26
For bricks suitable for light traffic	26	28

Which of these grades should be specified in any given district and for any given purpose is a matter wholly within the province of the buyer, and should be governed by the kind and amount of traffic to be carried, and the quality of paving bricks available.

18. *Culling and Retesting.*—Where, under Sections 15 and 16, a lot or portion of a lot of brick is rejected, either by reason of failure to show a low enough average test or because of tests

above the permissible maximum, the buyer may at his option permit the seller to regrade the rejected brick, separating out that portion which he considers at fault and retaining that which he considers good. When the regrading is complete, the good portion shall be then resampled and retested, under the original conditions, and if it fails again either in average or in permissible maximum, then the buyer may definitely and finally reject the entire lot or portion under test.

19. *Payment of Cost of Testing.*—Unless otherwise specified, the cost of testing the material as delivered or prepared for delivery, up to the prescribed number of tests for valid acceptance or rejection of the lot, shall be paid by the buyer. (See also Section 23.) The cost of testing extra samples made necessary by the failure of the whole lot or any portion of it, shall be paid by the seller, whether the material is finally accepted or rejected.

II. VISUAL INSPECTION.

It shall be the right of the buyer to inspect the bricks, subsequent to their delivery at the place of use, and prior to or during laying, to cull out and reject upon the following grounds:

20. All bricks which are broken in two or chipped in such a manner that neither wearing surface remains intact, or that the lower or bearing surface is reduced in area by more than one-fifth. Where bricks are rejected upon this ground, it shall be the duty of the purchaser to use them so far as practicable in obtaining the necessary half-bricks for breaking courses and making closures, instead of breaking otherwise whole and sound bricks for this purpose.

21. All bricks which are cracked in such a degree as to produce defects such as are defined in Section 20, either from shocks received in shipment and handling, or from defective conditions of manufacture, especially in drying, burning or cooling, unless such cracks are plainly superficial and not such as to perceptibly weaken the resistance of the brick to its conditions of use.

22. All bricks which are so off-size, or so misshapen, bent, twisted or kiln-marked, that they will not form a proper surface as defined by the paving specifications, or align with other

bricks without making joints other than those permitted in the paving specifications.

23. All bricks which are obviously too soft and too poorly vitrified to endure street wear. When any disagreement arises between buyer and seller under this item, it shall be the right of the buyer to make two or more rattler tests of the brick which he wishes to exclude, as provided in Section 2, and if in either or both tests, the bricks fall beyond the maximum rattler losses permitted under the specifications, then all bricks having the same objectionable appearance may be excluded, and the seller shall pay for the cost of the test. But if under such procedure, the bricks which have been tested as objectionable, shall pass the rattler test, both tests falling within the permitted maximum, then the buyer cannot exclude the class of material represented by this test and he shall pay for the cost of the test.

24. All bricks which differ so markedly in color from the type or average of the shipment, as to make the resultant pavement checkered or disagreeably mottled in appearance. This Section shall not be held to apply to the normal variations in color which may occur in the product of one plant among bricks which will meet the rattler test as referred to in Sections 15, 16, and 17, but shall apply only to differences of color which imply differences in the material of which the bricks are made, or extreme differences in manufacture.

DISCUSSION.

Mr. A. N. Talbot.

Mr. Talbot.—May I make one remark in connection with this report? It seems well to call attention to one other reason for allowing a prescribed fluctuation or range in the results of the rattler test beside the one of natural variation in quality of the paving-brick material, and also for providing for a second test; and this reason is that it is appreciated by the committee that the rattler test is at best an imperfect method of testing, and that some variation in results may be due to accidental conditions of the rattler test. Such accidental variations of the testing machine are also expected to be covered in the range of allowance made.

The President.

The President.—The Chair will take the liberty of expressing his views on a point that is in the province of this committee and applies to many materials. I am thoroughly impressed with the desirability of designating definitely in specifications the number of samples that shall be taken. In many specifications a range as to the number of samples is given, and the number is left to the judgment of the engineer. My experience has proven that that is a very dangerous provision, because we find that in very many cases in commercial life the contractor pays for the inspection. In many lines of construction that has become almost a universal custom. In such cases the contractor naturally wants to get the inspection at the lowest possible price. The engineer or architect, or city official, desires to have his material under some recognized specifications, but if there is a range as to the number of tests, he is apt to accept the fewest possible number in order to have the work performed for the least money. Now, if inspection is worth anything, if testing is worth anything, I think it is just as important that a definite number of tests to a given quantity of material should be specified, as to specify how the tests shall be made.

REPORT OF COMMITTEE C-4

ON

STANDARD SPECIFICATIONS AND TESTS FOR CLAY AND CEMENT SEWER PIPES.

Since the presentation of the last report of the committee we have had a number of meetings. After the last annual meeting the entire subject had been separated into a large number of integral parts, and sub-committees had been appointed, each one of which was requested to report on the questions embraced in one or more of the parts which were assigned to it.

It was expected that all of the reports would be presented in the early part of this year, so that a progress report of substantial value could be presented at this time. Unfortunately, several of the principal sub-committees have not yet completed their reports owing to the pressure of other business.

As fast as the material is received from these sub-committees, it is being classified and studied.

It is now confidently expected that before the next annual meeting the committee will be able to reduce all the data on hand to the form of a full report. After all the members of the committee have considered its conclusions, it will then be presented to the Society.

Respectfully submitted on behalf of the committee,

RUDOLPH HERING,
Chairman.
A. J. PROVOST, JR.,
Vice-Chairman.

E. J. FORT,
Secretary.

REPORT OF COMMITTEE C-6

ON

STANDARD TESTS AND SPECIFICATIONS FOR DRAIN TILE.

Committee C-6 hopes to present definite specifications to the Society at the June meeting, 1914, for consideration and possible adoption as standard.

Preliminary to the final preparation of such specifications a considerable amount of investigation work has been and is still under way, both directly under the committee and separately, in laboratories working in cooperation. The committee numbers in its membership the responsible heads of the following testing laboratories: Agricultural Engineering, University of Minnesota; College of Engineering, University of Wisconsin; Tile Testing Laboratory of the Universal Portland Cement Co., Chicago, Ill.; Engineering Experiment Station, Iowa State College, Ames, Iowa; Mechanics Department, University of Nebraska; Mechanics Section of Engineering Experiment Station, University of Illinois; City Testing Laboratory, St. Louis.

All of the above laboratories, save possibly one, are carrying on investigations directly in line with the work of Committee C-6. Specifically, Mr. Mont Schuyler, of the City Testing Laboratory, St. Louis, has constructed and tested a new water-bearing device for applying concentrated loadings in pipe tests. Prof. A. N. Talbot, of the University of Illinois, and Mr. C. W. Boynton, of the Universal Portland Cement Co., have devised and tested inexpensive tile testing machines, and convenient bearings for concentrated loadings in tile tests. Dean F. E. Turneaure, of the University of Wisconsin, is undertaking for Committee C-6 a series of tests of the inter-relations of bearing strength, absorption, and the effects of freezing and thawing on different grades of tile. Prof. John T. Stewart, of the Agricultural Engineering Department, University of Minne-

sota, has been making a series of tests of tile by different methods. The Engineering Experiment Station of the Iowa State College, Ames, Iowa, has just published a 181-page bulletin, giving the results of six years' active and extensive investigations of failures of drain tile and sewer pipe, of actual weighings and the mathematical theory of loads on pipes in ditches. In this bulletin are also given different methods of testing drain tile, including the detailed results of actual tests of more than 1000 different specimens of drain tile and sewer pipe, by a method of distributed loading for which the claim is made, in view of the results of comparison with actual failures in ditches, that it closely develops in laboratory tests substantially the same strengths which the pipes develop in actual ditch conditions.

As stated in our 1912 report,[1] Committee C-6 is organized for carrying on its work, in five sub-committees, as follows:

I. On Tests: Prof. A. N. Talbot, Chairman.
II. On Data of Manufacture of Clay Tile: G. W. Gates, Chairman.
III. On Data of Manufacture of Cement Tile: P. H. Atwood, Chairman.
IV. On Durability of Tile: Dean F. E. Turneaure, Chairman
V. On Construction and Field Specifications: Prof. J. T. Stewart, Chairman.

Mr. P. H. Atwood has resigned, and the vacancy has not yet been filled.

The Sub-Committee on Tests has under special investigation the methods of making bearing-strength tests of drain tile, and has now narrowed its work to the special investigation of two principal methods:

First, the method of distributed loadings over 90-deg. strips at top and bottom, which is claimed to develop laboratory strengths substantially equal to actual strengths in ditches;

Second, the method of concentrated loadings over narrow strips at top and bottom, which is claimed to be more rapid and convenient, and hence less expensive.

[1] *Proceedings*, Am. Soc. Test. Mats., Vol. XII, p. 72 (1912).

To decide whether one of the above methods shall be adopted as standard, and which, or whether both should not be adopted, and to determine the ratio of results by the two methods, the Sub-Committee on Tests has planned a series of about 600 comparative tests, of both cement and clay tile, of 8, 16, and 24-in. diameters, to be specially selected for uniform quality.

Owing to the varied manufacturing interests involved, and their great financial importance, Committee C-6 has experienced unexpected delay and difficulty in securing the specimens for these tests. After efforts by the sub-committees on manufacture of clay and cement tile had failed, and after much delay, the Engineering Experiment Station of the Iowa State College came to the relief of the committee by ordering the manufacture at its expense of the cement tile needed, from a factory at Jefferson, Iowa, selected by the cement tile manufacturers for that purpose. Also the Clay Products Publicity Bureau, of Kansas City, Mo., has now agreed to select and deliver the clay tile at Ames, Iowa, at an early date.

As soon as these specimens are ready, the tests are to be carried out by employees of the laboratories already named, with the assistance of as many members of Committee C-6 as can find it possible to be present. It is hoped that the work can be done in July or August, 1913.

The Sub-Committees on Data of Manufacture of Clay and of Cement Tile are expected to collect valuable data of the various materials and processes of manufacture, for inclusion in the report of Committee C-6, but not in the specifications for drain tile, which should deal, it is believed, with the qualities of the finished product rather than methods of manufacture.

The Sub-Committee on Durability of Tile has under experimental investigation the absorption test, and a freezing and thawing test, and the relation of the two to bearing strength and modulus of rupture. It is proposed to make a series of tests of soft and of hard-burned clay tile, from surface clays and from shale, together with similar tests of cement tile of lean and rich mixtures, and made with different percentages of water, and by different machines.

This sub-committee also purposes to collect by correspon-

dence as much data as practicable relating to the effect of soil and ground-water alkalies and acids on the durability of tile. Laboratory tests along these lines have been discussed, but not favored. It is believed that the preliminary essential to any laboratory tests of drain tile of any kind must be the correct determination of the actual field conditions to which tile is to be exposed, by extensive field observations.

Such a field investigation of the effect of soil and ground-water acids and alkalies would require years of observations to be of much value, and it is understood that the United States Reclamation Service is about to inaugurate such tests. Hence it seems useless for Committee C-6 to make short tests along this line.

The Sub-Committee on Construction and Field Specifications has been collecting data on construction methods, and on present specifications for construction work, and practicable improvements therein.

As already stated, Committee C-6 plans to present definite standard specifications for drain tile and for laying of drain tile at the next annual meeting of the American Society for Testing Materials, in 1914, with recommendation for their adoption. The committee desires to outline at this time some of the questions which it has under consideration as to such standard specifications, without expressing any committee decision or opinion, but in the hope of arousing some illuminating discussion and criticism from the members of the Society at large.

Most, if not all, of the clauses which should be included in Standard Specifications for Drain Tile and for Pipe Laying will fall under one of four heads:

I. Specifications for Standard Methods of Testing Drain Tile;
II. Specifications of Quality of Drain Tile from Numerical Results of Tests;
III. Specifications for Inspection, and of General Qualities of Drain Tile;
IV. Specifications of Laying of Drain Tile.

These groups may be taken up in order.

I. SPECIFICATIONS FOR STANDARD METHODS OF TESTING DRAIN TILE.

Committee C-6 does not wish to discuss this subject at this time. It has under experimental laboratory investigation different methods for testing the bearing strength, absorption, and resistance to freezing and thawing, but the committee has not yet reached any final conclusions as to definite specifications.

II. SPECIFICATIONS OF QUALITY OF DRAIN TILE FROM NUMERICAL RESULTS OF TESTS.

In this group two tests are of principal importance; namely, bearing strength tests, and absorption tests.

Specifications for Minimum Bearing Strength of Drain Tile.—Two methods of specifying the minimum bearing strengths of drain tile are under consideration by Committee C-6.

One method is to specify arbitrary minimum strengths per linear foot, based on many tests of good pipe, just as the tensile strength of cement is specified as indicating its quality, without reference to any stresses it must sustain in structures. This method alone does not provide safety against the cracking of pipes in ditches now sometimes experienced in all the large sizes of both drain tile and sewer pipe, for pipe of the quality now often made by well-established factories has cracked in a number of instances in deep and wide ditches, though sound and satisfactory in every way for ordinary moderate depths and widths.

The other method is to specify the ordinary maximum loads on pipes in ditches of different dimensions, and for different ditch-filling materials, and further to specify a minimum safety factor of bearing strength for the drain tile (or the tile drain). Combined with this a requirement would also be inserted for a minimum *quality* bearing strength, to aid in shutting out pipe which might disintegrate. In favor of this method it is urged that at least $75,000,000 worth of sewer pipe and drain tile lines are constructed annually in the United States alone, in all of which safe bearing strength of the pipe is an absolutely essential factor, yet in all of which engineers up to the present time have simply guessed at the strength of the pipe as related to the loads, just as was the custom in bridge construction until the

last century. It is argued, especially in view of the accusing evidence of miles upon miles of cracked pipe, that the time has now come for engineers to quit guessing on a matter of such great and vital importance, and instead to calculate the loads and to test the strengths.

It is evident that the first essential to this desirable end is

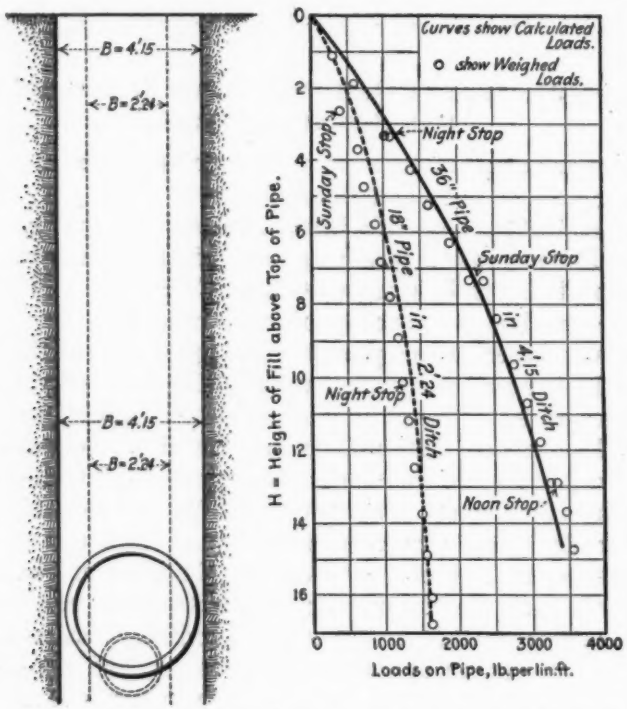


FIG. 1.—Diagram showing Comparison of the Weighings of Actual Loads on Pipes in Ditches (in Two Experiments) with the Calculated Loads.

a correct theory of the loads on pipes in ditches, a theory well backed up by reliable experimental data.

A mathematical theory of loads on pipes in ditches was presented by Mr. Marston before this Society in 1912.[1] This theory has since been checked closely by quite extensive weighings of actual loads on pipes in ditches, and by comparisons

[1] *Proceedings*, Am. Soc. Test. Mats., Vol. XI, p. 834 (1911).

with all known cases of actual cracking of pipes in ditches, as published in detail on pages 65 to 88 of Bulletin No. 31, "The Theory of Loads on Pipes in Ditches, and Tests of Cement and Clay Drain Tile and Sewer Pipe," of the Iowa State College Engineering Experiment Station, Ames, Iowa. Owing to the great importance of the subject, the committee has decided to include herewith a brief summary of the results in this report.

Fig. 1 (Fig. 21 of Bulletin 31) shows the close correspon-

TABLE I.—ORDINARY MAXIMUM LOADS ON DRAIN TILE AND SEWER PIPE IN DITCHES, LB. PER LIN. FT.

FOR CLAY, AND ALL COMMON SOILS, OR COMBINATIONS OF SOILS, EXCEPT SAND AND LOAM.

Height of Fill Above Top of Pipe, ft.	Breadth of Ditch at Top of Pipe.				
	1 ft.	2 ft.	3 ft.	4 ft.	5 ft.
2	210	470	730	1 000	1 240
4	340	840	1 330	1 870	2 370
6	430	1 140	1 900	2 630	3 410
8	490	1 380	2 360	3 360	4 460
10	520	1 570	2 760	3 980	5 270
12	540	1 730	3 100	4 560	6 050
16	570	1 940	3 660	5 510	7 440
20	580	2 090	4 070	6 280	8 610
24	580	2 180	4 380	6 910	9 590
30	580	2 260	4 700	7 590	10 780
FOR SAND AND LOAM UNMIXED WITH OTHER SOILS.					
2	180	410	650	890	1 110
4	270	710	1 170	1 640	2 100
6	310	910	1 590	2 270	2 970
8	340	1 070	1 910	2 820	3 720
10	350	1 180	2 180	3 260	4 380
12	360	1 250	2 400	3 650	4 980
16	360	1 350	2 710	4 260	5 940
20	360	1 400	2 910	4 700	6 660
24	360	1 430	3 050	5 010	7 230
30	360	1 440	3 150	5 340	7 830

NOTE.—For dimensions of ditch not given the loads shall be interpolated between the loads in the table.

dence of the calculated and the actual loads in two of the most important tests at Ames, covering a range of pipe from 18 to 36 in. and of ditches from 2.24 to 4.15 ft. wide, and from 0 to 18 ft. deep.

The accuracy of the theory of loads on pipes in ditches was further demonstrated by an analysis of 47 cases of actual cracking of pipes in ditches, as given in Table 15, pages 84 and 85, of Bulletin No. 31, and by a comparison of calculated with

weighed loads in 5 tests by Mr. F. A. Barbour. (See page 81 of Bulletin No. 31.)

After making proper allowance for the worst conditions of filling materials ordinarily to be anticipated, the theory of loads on pipes in ditches leads (see page 175 of Bulletin No. 31) to Table I, which gives the ordinary maximum loads on drain tile and sewer pipe in ditches.

The above maximum loads usually occur at the time of the first *very thorough* flooding of the ditch-filling materials after the ditch is refilled, but sometimes may not occur for years. Between times of extreme saturation of the ditch-filling materials the permanent loads are much smaller.

Specifications for Maximum Allowable Percentages of Absorption for Drain Tile.—In specifying maximum absorption requirements for drain tile, the question arises whether to specify the maximum allowable percentages for all materials or a different percentage for each material.

The principal object of the absorption requirement is to provide against pipe-shell material of such poor quality as to be in danger of disintegration.

It seems to be demonstrated that percentages of absorption found in excellent fire-clay pipe may be entirely too high for good shale pipe. Even surface-clay pipe of high porosity may sometimes stand freezing and thawing better than some denser shale pipe. Hence it is claimed that a different maximum allowable percentage of absorption should be specified for each general class of clay pipe and for cement pipe.

III. SPECIFICATIONS FOR INSPECTION AND OF THE GENERAL QUALITIES OF DRAIN TILE.

Committee C-6 has at present no questions to raise in this group, but would be glad of suggestions, especially as to defects which should cause rejection.

IV. SPECIFICATIONS FOR LAYING OF DRAIN TILE.

In this group of specifications Committee C-6 has under discussion the following questions:

1. In ordinary pipe laying, how far is it wise to specify special preparation of the bedding of the pipe?

The committee is considering whether to require shaping and careful bedding in granular material of a 90-deg. strip of the bottom of the pipe, with requirement of specially firm bearing at the outer edges of such strip.

2. In ordinary pipe laying, how far is it wise to specify careful tamping of the filling between the sides of the pipe and the sides of the ditch?

The committee is convinced that such tamping cannot be relied upon to prevent cracking of the pipe, the horizontal diameter of which is found to elongate usually less than 0.02 in. at each end before cracking, in sizes up to 30 in. in diameter. Side tamping, however, will give much added safety against collapse if the pipe should crack.

3. How far is it wise to require or permit bedding of pipes in concrete to make up for a deficiency in bearing strength?

It is obvious that prevention of cracking of pipes in ditches will often call for a choice between making extra strong pipe, at a largely increased cost, or of strengthening the pipe against cracking by bedding them in lean concrete in the ditch.

Respectfully submitted on behalf of the committee,

A. MARSTON,
Chairman.

J. T. STEWART,
Secretary.

NOTE.—Following the presentation of the report of Committee C-6, it was decided to refer to the committee, with power, the omission of the words distinguished by italics in the following sentence at the middle of the fifth page of the report as originally presented:

"This method alone does not provide safety against the cracking of pipes in ditches *now so prevalent in all the large sizes of both drain tile and sewer pipe, for pipe of the best quality now made will generally crack in deep and wide ditches, though sound and satisfactory in every way for ordinary moderate depths and widths.*"

The committee has changed the clause in question to read as follows, the words in italics showing the changes made:

"now *sometimes experienced* in all the large sizes of both drain tile and sewer pipe, for pipe of the quality now *often* made *by well-established factories has cracked in a number of instances* in deep and wide ditches, though sound and satisfactory in every way for ordinary moderate depths and widths."

The report is printed above in its revised form.—ED.

REPORT OF COMMITTEE C-7

ON

STANDARD SPECIFICATIONS FOR LIME.

The committee reports that since its authorization in June, 1912, it has held seven meetings. In addition the members have studied the problem individually from various standpoints, and have corresponded extensively with one another. As a result, the committee submits the appended proposed Standard Specifications for Lime with the recommendation that they be adopted by the Society. The work of the committee has been complicated by the various uses to which lime is put, and the variation in the chemical composition and physical characteristics allowed or desirable for different purposes.

Few materials have so wide a variety of application as lime. Less than one-half of the product is consumed in the building trades where it is used chiefly in the making of lime mortars and plasters, and as an addition to Portland-cement concrete and gypsum plaster. The remainder of the lime produced is consumed by the chemical trade, which embraces, besides agriculture, the manufacture of bleaching compounds, caustic alkali, gas, glass, paper, leather, sugar, soaps, oils and chemicals such as carbides, acetates, ammonia, etc. For these varied chemical uses, the physical qualities are less important than chemical composition, which may vary through various steps from practically pure calcium oxide to a lime in which the content of magnesium oxide may be about 40 per cent.

In the building trade, the qualities of greatest importance for making mortars are the sand-carrying capacity and strength developed; for plastering, the plasticity, spreading qualities, constancy of volume and strength. These are largely independent of chemical composition and are affected by the treatment of the lime after delivery to the user as well as by the process of manufacture. It was therefore deemed advisable to limit the specifications to requirements directed to securing the proper chemical composition and preparation by the manufacturer.

For quicklimes, chemical requirements are confined to specifying the content of calcium and magnesium oxides and limiting the content of carbon dioxide, which is important as indicating either completeness of calcination or the extent, if any, to which the lime has been spoiled by air-slaking, after manufacture. Physical requirements are limited to the percentage of waste or impurities which the different grades may contain.

For building and chemical hydrates, only the content of carbon dioxide and water are specified under chemical tests, as the total content of basic oxide will vary with the ratio of calcium and magnesium oxides present, and the consequent variation in the amount of water of hydration. The requirement that there shall be at least one per cent more water present in the hydrate than is required for the complete hydration of the calcium oxide insures complete hydration and acts as a check on the presence of an excessive amount of silica, iron oxide and alumina,—the impurities usually present in hydrates,—since the combinations they form with lime during calcination do not readily hydrate. For agricultural hydrate, the total content of magnesium and calcium oxide is important and is specified.

In considering the omission of tests to determine the strength of mortars, it must be remembered that quicklime is but a partially prepared and perishable material, and the strength of mortars made from it will depend largely on its treatment after leaving the manufacturer. For this reason, together with the fact that the standard methods in use for testing other cementitious materials are not well adapted to the testing of lime owing to its slow rate of hardening, the committee decided to omit requirements as to strength. It, however, believes them to be desirable and is still engaged in an effort to develop suitable tests to determine constancy of volume, ease of working and cementing value, and asks to be continued.

Respectfully submitted on behalf of the committee,

E. L. CONWELL,
Secretary.

H. S. SPACKMAN,
Chairman.

[NOTE.—The proposed Standard Specifications for Lime were referred back to Committee C-7 for further consideration.—ED.]

AMERICAN SOCIETY FOR TESTING MATERIALS

PHILADELPHIA, PA., U. S. A.

AFFILIATED WITH THE

INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

PROPOSED STANDARD SPECIFICATIONS

FOR

LIME.

Definition.

1. Lime is a product resulting from the calcination, at a temperature below the cintering point, of a material containing carbonates of calcium or calcium and magnesium, which may be or has been converted to a paste or a dry flocculent powder, by slaking.

Classifications.

2. Limes may be divided into two commercial forms:

(*a*) *Quicklime.*—A product coming from the kiln, without subsequent treatment, other than sorting, crushing or pulverization, which slakes on the addition of water. Quicklime may be shipped either as lump lime or pulverized lime. Lump lime shall be kiln size. Pulverized lime is lump lime reduced in size by mechanical means.

(*b*) *Hydrate.*—A dry flocculent powder resulting from the hydration of quicklime.

Grades and Classes.

3. (*a*) Quicklimes are divided into two grades:

Selected.—A well-burned lime, picked free from ashes, core, clinker or other foreign material.

Run-of-Kiln.—A well-burned lime without selection.

(*b*) Hydrates are divided into two classes:

Building and Chemical.—A lime hydrated to definite chemical proportions, and reduced to a fineness suitable for building purposes.

Agricultural.—A lime reduced to a powder by hydration. As calcium and magnesium oxides play an important but distinct part as fertilizers, agricultural hydrates are divided into two classes, namely, high-calcium and magnesian hydrates.

Basis of Purchase.

4. Where quicklime or hydrated lime is to be used for chemical or agricultural purposes, the desired content of calcium or magnesian oxide shall be specified in advance by the purchaser.

I. CHEMICAL PROPERTIES AND TESTS.

(*A*) *Sampling.*

Quicklime in Bulk.

5. When quicklime is shipped in bulk, the sample shall be so taken that it will represent an average of all parts of the shipment, from top to bottom, and shall not contain a disproportionate share of the top and bottom layers, which are most subject to changes. The sample shall comprise at least 10 shovelsful taken from different parts of the shipment. The total sample taken shall weigh at least 100 lb., and shall be crushed to pass a 1-in. ring, and quartered to provide a sample of the size required by the laboratory. The sample to be sent to the laboratory shall immediately be transferred to an air-tight container.

Quicklime in Barrels.

6. When quicklime is shipped in barrels, at least 3 per cent of the number of barrels shall be sampled. They shall be taken from various parts of the shipment, dumped, mixed and sampled as specified in Section 5.

Pulverized Quicklime or Hydrated Lime.

7. The sample taken from either pulverized quicklime or hydrated lime shall be a fair average of the shipment. It is recommended that where conditions permit, 3 per cent of the packages shall be sampled. The samples shall be taken from the surface to the center of the package. The sample to be sent to the laboratory shall immediately be transferred to an air-tight container.

(*B*) *Chemical Tests.*

Quicklime.

8. (*a*) Selected quicklime shall contain not under 90 per cent of calcium and magnesium oxides, and not over 3 per cent of carbon dioxide.

(*b*) Run-of-kiln quicklime shall contain not under 85 per cent of calcium and magnesium oxides, and not over 5 per cent of carbon dioxide.

9. Building and chemical hydrates shall contain not over 5 per cent of carbon dioxide, and not under 1 per cent of water in excess of that required to fully hydrate the calcium oxide present. **Building and Chemical Hydrates.**

10. (*a*) High-calcium agricultural hydrate shall contain not over 5 per cent of magnesium oxide, and not over 10 per cent of carbon dioxide; and shall contain not under 80 per cent of calcium and magnesium oxides figured on an anhydrous basis. **Agricultural Hydrates.**

(*b*) Magnesian agricultural hydrate shall contain not under 5 per cent of magnesium oxide, and not over 10 per cent of carbon dioxide; and shall contain not under 80 per cent of calcium and magnesium oxide figured on an anhydrous basis.

II. PHYSICAL PROPERTIES AND TESTS.

(*A*) *Quicklime.*

11. An average 5-lb. sample of selected or run-of-kiln quicklime shall be put in a box and slaked with sufficient water to produce a lime putty, which shall be allowed to stand for 24 hr., then washed through a standard 10-mesh sieve. Not over 3 per cent of the weight of selected quicklime, nor over 5 per cent of the weight of run-of-kiln quicklime, shall be retained on the sieve. The sample taken for this test shall not be crushed finer than will pass a 1-in. ring, either before being sent to the laboratory or at the laboratory. **Percentage of Waste.**

(*B*) *Hydrated Lime.*

12. (*a*) Building and chemical hydrates shall leave by weight a residue of not over 5 per cent on a standard 100-mesh sieve. **Fineness.**

(*b*) Agricultural hydrate shall leave no residue on a standard 4-mesh sieve, and shall leave by weight a residue of not over 10 per cent on a standard 20-mesh sieve.

III. PACKING AND MARKING.

(*A*) *Lump Lime.*

13. When not shipped in bulk, lump lime shall be packed in barrels, which may weigh either 200 lb. gross and contain approximately 185 lb. of lime, or 300 lb. gross and contain approximately 280 lb. of lime. **Packing.**

Marking. 14. The name of the manufacturer, grade and gross weight shall be legibly marked on each barrel. Marking shall be blue for selected and red for run-of-kiln quicklime.

(*B*) *Pulverized Lime.*

Packing. 15. Pulverized lime shall be packed either in cloth bags containing 167 lb., or in paper sacks containing 80 lb.

Marking. 16. (*a*) When shipped in cloth, the name of the manufacturer and the grade of lime from which it was prepared shall be legibly marked or tagged on each bag. The marking or tag shall be blue for selected and red for run-of-kiln quicklime.

(*b*) When shipped in paper, the name of the manufacturer and the grade of lime from which it was prepared shall be legibly marked on each sack. The marking shall be blue for selected and red for run-of-kiln quicklime.

(*C*) *Hydrated Lime.*

Packing. 17. Hydrated lime may be packed either in cloth bags containing 100 lb., or in paper sacks containing 40 lb.

Marking. 18. (*a*) When shipped in cloth, the name of the manufacturer and grade shall be legibly marked or tagged on each bag. The marking or tag shall be blue for building and chemical hydrates and red for agricultural hydrate.

(*b*) When shipped in paper, the name of the manufacturer and grade shall be legibly marked on each sack. The marking shall be blue for building and chemical hydrates and red for agricultural hydrate.

(*c*) The marking of agricultural hydrates shall show whether they are high-calcium or magnesian.

IV. INSPECTION AND REJECTION.

Inspection. 19. (*a*) All limes shall be subject to inspection.

(*b*) The lime may be inspected either at the place of manufacture or the point of delivery.

(*c*) The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the material ordered.

The manufacturer shall afford the inspector all reasonable facilities for inspection and sampling, which shall be so conducted as not to interfere unnecessarily with the operation of the works.

(*d*) The purchaser may make the tests to govern the acceptance or rejection of the lime in his own laboratory or elsewhere. Such tests, however, shall be made at the expense of the purchaser.

20. Unless otherwise specified, any rejection based on tests made in accordance with Section 19 (*d*) shall be reported within five working days from the taking of samples. **Rejection.**

21. Samples tested in accordance with Section 19 (*d*), which represent rejected lime, shall be preserved for five days from the date of the test report. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time. **Rehearing.**

DISCUSSION.

Mr. Humphrey. MR. RICHARD L. HUMPHREY.—I should like to ask what consideration has been given to the adhesive qualities of lime in the preparation of this specification.

Mr. Spackman. MR. H. S. SPACKMAN (*Chairman, Committee C-7*).—None at all. It was found impossible to develop a reliable test for adhesiveness; then again while the quality of the adhesiveness would be of value in the case of lime used for building purposes, it would be of no value where lime is used for agricultural or chemical purposes. We have to consider a very wide range of uses for lime, and not look at the specifications from the one standpoint of its use in mortars for building purposes.

Mr. Humphrey. MR. HUMPHREY.—When we deal with lime as a building material, its adhesive quality is fundamental, and it seems to me that a specification that does not deal with that particular phase of its value is defective. I do not criticise the report as a whole, and I regard the proposed specifications as an excellent step in the right direction; but I believe that before the specifications are adopted as specifications for building lime, the committee ought to seriously consider the point to which I have referred, as I believe the specifications will be of little value unless there is some measure of this quality of the lime. The word "lime" covers a wide range of material, and without something to measure its quality, the specification does not have very much value.

Mr. Spackman. MR. SPACKMAN.—The point is, can you suggest a test to measure the adhesive qualities of lime that is practicable for use? The committee was unable to find one. Lime, as you know, has no binding or adhesive qualities in itself; it is not self-hardening, as cement is, and its binding qualities are largely dependent upon conditions outside of the control of the manufacturer. Lime mortar hardens first by drying out, in the same manner as would clay or other non-cementitious plastic material. This hardening is only temporary and would disappear on the

mortar becoming wet. The permanent hardening of lime mortar is due to the absorption of carbonic acid from the air, which results in the formation of calcium carbonate; this is dependent on outside influences, such as the amount of carbonic acid in the air, the amount of moisture in the mortar, the thickness and density of the coating, in the case of plaster, or the permeability to air of the mass, in the case of masonry, temperature, etc. The hardening due to the absorption of carbonic acid is very slow and erratic, and cannot be measured with any accuracy by the ordinary testing machine when the mortar is made into briquettes before the 28-day period. Mr. Spackman.

As limes put on the market, with the exception of those in the form of hydrate, are very perishable, it would be impracticable to hold the shipments until the adhesive qualities of the lime were tested. Instead, therefore, of providing a direct test for adhesive qualities we have tried to insure their presence by providing that the lime shall be of proper chemical composition, correctly burned, and otherwise prepared in a manner best qualified to insure the maximum adhesiveness or binding property in mortars prepared from it under average conditions of use. It must be remembered, however, that the adhesive or binding quality of the lime depends not only on the chemical composition and method of preparation, but also on the treatment of the lime after it gets into the hands of the user. Its ultimate binding qualities will depend as much upon how it is slaked, how long it is aged, how the mortar is applied, etc., as upon the quality of the lime.

In view of these facts we did not feel that we were justified in prescribing any definite requirement for strength. A further study of the problem may enable us to do so, but at present we feel that any requirement that lime mortars should give a certain strength at the 7-day period would be unwarranted.

MR. F. P. VEITCH.—I think the specifications are decidedly faulty; they are lacking in definiteness, poorly arranged, and decidedly unfair to the user of lime. The definition of lime permits in making it the use of a material containing small percentages of calcium or magnesium carbonates. While it is true an attempt is made to guard against this later on, the matter is really left open by the statement in Section 4 of the Mr. Veitch.

Mr. Veitch. specifications that "where quicklime or hydrated lime is to be used for chemical or agricultural purposes, the desired content of calcium or magnesian oxides shall be specified in advance." It seems to me that this statement qualifies other provisions of the specifications. Pulverized lime is defined as "lime reduced in size by mechanical means." A member jokingly remarked that a lump of lime hit with a sledge hammer is pulverized lime under this clause. The word "pulverized" has not the meaning conveyed here; I believe it is not the commercial term. What is referred to is known usually as "ground lime" or "crushed lime."

The statement in Section 3 under the head of "Agricultural," reading, "As calcium and magnesium oxides play an important but distinct part as fertilizers," etc., I think should be omitted. The inference that there is a commercial demand for magnesium lime in agriculture is, I think, entirely unwarranted. I have already spoken of the provision which required the purchaser to specify the quality, that is, the percentage of calcium and magnesium oxides desired when the lime is to be used for chemical or agricultural purposes. This, in a way, it seems to me, nullifies the specifications. If the percentage of lime and magnesium oxide were not specified, the delivery need comply with no specifications. In Section 8 (*a*) and (*b*), under "Chemical Tests," is the statement, "Selected quicklime shall contain not under 90 per cent of calcium and magnesium oxides and not over 3 per cent of carbon dioxide. Run-of-kiln quicklime shall contain not under 85 per cent of calcium and magnesium oxides and not over 5 per cent of carbon dioxide." There is no requirement as to the percentage of lime; the material might be entirely magnesium oxide, under that clause. In Section 9, under "Building and Chemical Hydrates," is the statement, "Building and chemical hydrates shall contain not over 5 per cent of carbon dioxide, and not under 1 per cent of water in excess of that required to fully hydrate the calcium oxide present"; but there is no limit to the amount of moisture. Section 10 (*a*) reads: "High-calcium agricultural hydrates shall contain not over 5 per cent of magnesium oxide, and not over 10 per cent of carbon dioxide; and shall contain not under 80 per cent of calcium and magnesium oxides figured on an

anhydrous basis." Limewater will comply with that clause. It seems to me also that the statement in Section 12 (*b*) that "agricultural hydrate shall leave by weight a residue of not over 10 per cent on a standard 20-mesh sieve," is pretty severe on the user; that is a very large residue. **Mr. Veitch.**

The features I have pointed out substantiate, I think, my statement that the specifications are very faulty, being indefinite, poorly arranged and unfair to the user of lime.

If it is proper at this time, I would move that these proposed specifications for lime be referred back to the committee for further consideration, to be brought up at the next meeting; and I should like to suggest further, if it is in order, that the personnel of the committee be suitably enlarged. There is, for example, no representative of the agricultural interests on the committee, and there should be such representation, it seems to me, if this committee is going to make specifications for agricultural limes; although I do not see why we should have specifications for agricultural lime different from those for any other lime. The farmer wants pure lime just as much as the most exacting chemical industry. He does not want to pay freight on a lot of water or silica; he wants straight lime.

MR. HUMPHREY.—I wish to second the motion and in doing so I wish to say that this is no reflection on the committee. The committee has made progress and has tentative specifications in print. I do not think that any interests will be seriously handicapped by delaying action on these specifications for another year. A casual reading of the report shows that the committee has left out many things, and I do not think the Society would be justified in sending out these specifications to letter ballot at this time and in their present form. **Mr. Humphrey.**

MR. W. E. EMLEY.—An examination of these specifications will show that hydrated lime is defined as a dry flocculent powder. It would therefore be impossible to ship a putty or milk of lime as hydrated lime. The agricultural part of these specifications was passed upon by Mr. Wheeler of the Rhode Island Experiment Station, who is recognized as one of the highest, if not the highest, authority on agriculture in the country. The use of magnesian lime for agriculture is sometimes desirable. In bulletins published by the United States **Mr. Emley.**

Mr. Emley. Department of Agriculture, as well as the Experiment Stations, the statement has frequently been made that for ordinary agricultural purposes a ratio of two of available calcium oxide to magnesium oxide should be maintained in the soil. I am borne out in this statement by Mr. Fippins of Cornell University.

In regard to specifying lime for chemical purposes: it is almost an endless task, because in the first place, lime is used for hundreds, if not thousands, of different chemical purposes, and there would have to be separate specifications for each purpose. Moreover, for several of these purposes, different manufacturers require different kinds of lime. They frequently have nothing except their own personal experience on which to base this requirement. They are not sure that their method is any better than the other man's, but judging from their experience, they demand a particular kind of lime. For instance, in the paper business, some men require a dolomitic lime and say there must be 40 per cent or more magnesia in their lime. Other men say that 15 per cent gives a good product and demand 15-per-cent-magnesian lime. In the iron industry, some sections demand a high-calcium limestone for the flux and some dolomitic. They have not been able to agree among themselves, so I do not see how we can be expected to write specifications for the paper industry. When a man goes on the market to buy pulverized lime, the first question he is asked is, "What size do you want?" Different men want it for different purposes and will require different sizes. It seems to me that it is impossible, without greatly and unnecessarily multiplying the number of specifications, to attempt to cover either the chemical or pulverized fields.

Mr. Wig. MR. R. J. WIG.—The first impression I got from reading these lime specifications was the same as that obtained by Mr. Veitch and Mr. Humphrey, that the specifications are very inadequate and poorly drawn; but I believe it is rather a matter of form than substance that gives this impression on first reading.

I think the committee has done very good work in so far as building lime is concerned, and has presented specifications which perhaps cover the field as well as it can be covered at the present time. As long as there are no specifications for build-

ing lime this is at least a good start toward such specifications. I should like to see the part which relates to building lime referred to letter ballot of the Society and adopted. **Mr. Wig.**

MR. CLOYD M. CHAPMAN.—As a member of this committee, I should like to point out that all of the points raised by Mr. Veitch have been much discussed at several meetings. I did not note down and cannot recall all of his objections, but let us take, for instance, his objection to the definition of lime. He states that under the definition as it stands a material which contains only a small percentage of calcium and magnesium oxide would be a "lime." I should like to ask if he thinks such a material could "be converted to a paste or a dry flocculent powder, by slaking." The percentage of calcium oxide must be high enough for slaking, and if it is, it is high enough for some purposes. Lime, for many purposes, does not have to be pure, but according to the definition it must have enough calcium and magnesium oxide to "be converted to a paste or a dry flocculent powder, by slaking." **Mr. Chapman.**

The other objections raised have the same general weakness. The specifications are more complete than they appear to be on the surface. Milk of lime cannot be sold as a hydrate under these specifications owing to the maximum amount of water not being specified, for the reason already stated by a previous speaker; namely, that hydrated lime must be "a dry flocculent powder."

And so with the other objections that have been raised; they are weak; none of them are new; and they have already been thoroughly discussed by the committee. The committee itself is not at all satisfied with these specifications as they now stand. It is a first attempt, a step in the right direction, which we hope will lead ultimately to satisfactory specifications. It is a fact that we are now where the steel industry was fifty years ago. What chance would the committees on specifications for iron and steel have had fifty years ago for framing specifications such as we have to-day? Not a chance in the world. We cannot draw as perfect specifications now as we will when we know more about the subject. I think the objections raised have been made without careful consideration and proper study of the proposed specifications. If Mr. Veitch could have

Mr. Chapman. attended some of the meetings of this committee the objections he has now raised would doubtless have been very largely explained to his satisfaction.

The President. THE PRESIDENT.—The motion is to refer the report back to the committee for further consideration with the understanding that it will be printed in the Proceedings. Are you ready for the question?

Mr. Spackman. MR. SPACKMAN.—Under ordinary conditions I think such a course would be a very proper one, but this committee originated out of a crying need in the lime industry. At present there is absolutely no standard, no measure of quality, no method of deciding what is or what is not lime. As far as the general market is concerned anything that is white and will slake may be sold as lime. At the annual meeting of the National Lime Manufacturers' Association, held in New York, January, 1912, the need of a standard specification was one of the most important subjects of discussion, and by resolution the American Society for Testing Materials was requested by the National Lime Manufacturers' Association to formulate standard specifications for limes, and as a result of that action this committee was appointed. If the recommended specifications are not accepted, I fear that the lime manufacturers as a whole will be bitterly disappointed. They look to us to give them something after a year and a half of waiting. Even though the proposed specifications are far from perfect, they are a step forward that will assure both manufacturer and consumer that lime of improper composition or of improper manufacture cannot be placed on the market.

I should like to answer at this time a few of the other questions in this connection. In regard to impurities, it is well known that any lime that contains much over 10 per cent of clay matter will not slake. I would also point out that the first page of the specifications is largely definitive of the terms used in the body of the specifications, and should not be considered separately from the same.

The other questions raised by Mr. Veitch have, I think, been pretty well answered, with the exception perhaps of the question he raised as to the substitution of the term "pulverized lime" for "ground lime." We admit that the use of the expres-

sion "pulverized lime" is a departure from common usage, but it was made because a great many people, especially farmers, when they hear or see the expression "ground lime" think that it is some special kind of lime to be used on the ground for fertilizing purposes, and do not realize that it is simply lime that has been pulverized by grinding. Mr. Spackman.

Referring to the statement that there is no provision as to the fineness to which the lime may be ground, my answer is that we simply stated that pulverized lime shall be broken by mechanical means to distinguish it from that reduced by slaking. We did not consider the size to which it was to be broken, as this varies greatly, according to the use to which the lime is to be put. One use may require that it must be broken down to such size that it will pass through a quarter mesh sieve, and that not more than 10 per cent shall be retained in a 20-mesh sieve. Another use may require that it shall be much coarser, and still another may require the same fineness as cement.

MR. CHARLES WARNER (*by letter*).—As a member of Committee C-7, representing manufacturers of lime, I have been greatly interested in the progress towards standardizing lime products. To consumers as well as manufacturers the great variety of grades, the different degrees of preparation, and the styles and weights of packages have been most confusing; with the result that lime has frequently been used for wrong purposes at large loss to consumers, and expense, trouble and misunderstanding on the part of the manufacturers. Mr. Warner.

Due to the increasing use of hydrated lime and the new brands constantly coming on the market, each with its own standard of quality and package, the confusion, misunderstanding, and faulty and unsafe use of these products is steadily increasing.

Considerable quantities of hydrated lime of uncertain and unsafe composition are now finding their way into the highest class of construction and chemical uses. At the best such grades are only suitable for agricultural use.

It is therefore time for this Society to act in the interest of both consumers and engineers, and I sincerely trust that it will give some stamp of approval, that may be of prompt public benefit, to the thoroughly drafted report of the committee.

Mr. Wig. MR. WIG.—I move as an amendment to the motion, to refer back to the committee those sections of the specifications referring to agricultural and chemical lime, but not the sections referring to building lime. [Amendment accepted by Mr. Veitch.]

Mr. Humphrey. MR. HUMPHREY.—The specifications proposed by the committee cover building, chemical and agricultural lime. It seems to me unwise to attempt to separate these specifications here by vote. The logical course would be to refer the whole report back to the committee so that the committee may report next year on separate specifications for the above three classes of lime. While I appreciate the desire of the committee to have these specifications referred to letter ballot now, I do not think it will hurt the cause to have action postponed for another year.

[Mr. Wig's amendment was then put to vote and lost, whereupon Mr. Veitch's original motion to refer the specifications back to the committee for further consideration was adopted.]

REPORT OF COMMITTEE D-1

ON

PRESERVATIVE COATINGS FOR STRUCTURAL MATERIALS.

Owing to the early meeting of the Society last year, Committee D-1 did not render any report and therefore the present report shows the progress made since the last report of this committee, which appears in the Proceedings for 1911, page 173. The committee has held four meetings since July 1, 1911.

Much against the wishes of the committee, Mr. S. S. Voorhees, who had been chairman for about ten years, insisted on being relieved and after unsuccessful efforts to cause him to change his mind his resignation as chairman was accepted at a meeting held November 26, 1912. The committee, on accepting Mr. Voorhees' resignation, unanimously adopted the following resolution:

"Committee E, now Committee D-1, was appointed before the Fifth Annual Meeting of the American Society for Testing Materials and made its first report to the Society in 1903. Practically ten years have passed since this committee was organized. We believe that a large part of the success of the committee's work has been due to the interest, good judgment, and the effective personality of its chairman, Mr. S. S. Voorhees, who, after ten years of labor, feels called upon to resign the post of chairman.

"It is with great regret that Committee D-1 accepts Mr. Voorhees' resignation, and in doing so, desires to express to Mr. Voorhees, on behalf of the committee and its members, individually, the high regard in which he is held, and to pledge to him a continuance of this regard, and an earnest hope for his future welfare and happiness.

"*Therefore, be it Resolved*, That a copy of the above declaration be inserted in the minutes of this committee, and that a copy of this preamble and resolution be suitably engrossed and presented to Mr. Voorhees."

Committee D-1 now has fifty-three members and that a large majority of them take active interest in the work done is shown by the fact that at the meeting held on April 18, 1913, in Washington, twenty-eight members attended, and among those

who were unable to attend were a number who have done a great deal of work.

This committee has been very conservative in presenting specifications and at this meeting, after being in existence for ten years, submits its first recommendation of a specification for adoption by the Soicety, this being a specification for raw linseed oil made from North American seed. The data upon which this specification is based have been collected by the committee during several years of careful and painstaking work.

There are also presented at this meeting certain "Proposed Standard Definitions of Terms used in Paint Specifications," with a recommendation that they be adopted by the Society.

The work of the old Sub-Committee J on White Paint Tests having been completed with the installation of the Arlington test fence, this sub-committee has been discharged and a new Sub-Committee J on Inspection of the Arlington Test Fence has been created.

The committee has adopted the following rules for the guidance of its sub-committees:

1. Each sub-committee shall elect a secretary, who shall keep minutes of its meetings, etc., assist the chairman of the sub-committee in correspondence, notifying the members of meetings, etc., and confer with the Secretary of Committee D-1, in the preparation of reports.

2. All records of sub-committees and its officers shall ultimately be transmitted to the Secretary of Committee D-1, for filing.

3. No expense shall be incurred by any sub-committee except for postage or stationery, unless previously authorized by the Advisory Committee. Statements of the expenses of sub-committees shall be sent to the Secretary of Committee D-1, for payment quarterly dating from July 1.

4. These rules shall go into effect at once.

In addition to the work on hand it is expected to take up the study of volatile thinners other than turpentine, at an early date.

Sub-Committee A, the Advisory Committee, has held three meetings; but as this sub-committee simply acts when it is not advisable to call a meeting of the whole committee, it has no formal report to render.

Detailed reports are appended from Sub-Committee B on the Inspection of the Havre de Grace Bridge, Sub-Committee C on the Testing of Paint Vehicles, Sub-Committee D on the

Inspection of Steel Plates at Atlantic City, Sub-Committee E on Linseed Oil, Sub-Committee F on Definitions of Terms used in Paint Specifications, and the old Sub-Committee J on Testing White Paints. Sub-Committee G on the Influence of Pigments on Corrosion, Sub-Committee H on Methods of Analysis of Paint Materials, Sub-Committee I on Varnish, and the new Sub-Committee J on Inspection of the Arlington Test Fence, have no formal reports to present. The chairman of Sub-Committee G on the Influence of Pigments on Corrosion, recommends that this sub-committee be discharged, but no action has been taken on this recommendation.

The committee is indebted to various experts for valuable laboratory work. This is especially the case in the work of Sub-Committees C and J. In the report of Sub-Committee C the names of those making the tests appear. This is not the case in the report of Sub-Committee J, and the committee therefore takes this occasion to express its thanks to F. W. Smither, J. H. Bower, and G. C. Schmidt of the Bureau of Chemistry, and A. N. Finn of the Bureau of Standards, for the very complete series of analyses of the pigments; to A. C. Belden of the National Lead Co. for the classification tests on the pigments; and to B. J. Howard of the Bureau of Chemistry for the complete series of microphotographs.

The detailed reports of the various sub-committees follow this report.

Respectfully submitted on behalf of the committee,

PERCY H. WALKER,
Chairman.

G. W. THOMPSON,
Secretary.

REPORT OF SUB-COMMITTEE B ON INSPECTION OF THE HAVRE DE GRACE BRIDGE.

Growing out of reports of several sub-committees in December, 1904, previously appointed to study and devise methods with recommendations for carrying these out, the Havre de Grace Bridge tests were inaugurated in the summer and autumn of 1906 through the courtesy of the Pennsylvania Railroad Co. in placing at the disposal of the committee such part of their new bridge over the Susquehanna River as might be determined necessary.

To communications addressed to prominent paint manufacturers of the country stating the opportunity offered for such a comparative service test never previously undertaken under like circumstances, replies were received from sixteen expressing their preparedness to enter the trial test. The expenses of this test were assumed by the several competitors under an estimate of cost by the committee and a *pro rata* assessment.

LIST OF CONTRIBUTORS.

Name.	Address.	No. of Paints furnished.
Devoe & Reynolds	New York City, N. Y	2
Eagle White Lead Co	Cincinnati, Ohio	1
Felton, Sybley & Co	Philadelphia, Pa	1
Frazier Paint Company	Detroit, Mich	1
Harrison Brothers	Philadelphia, Pa	1
Lowe Brothers	Dayton, Ohio	1
John Lucas & Co	Philadelphia, Pa	1
John W. Masury & Son	Brooklyn, N. Y	1
C. L. Miller	New York City, N. Y	1
National Lead Company	Brooklyn, N. Y	1
Patton Paint Company	Milwaukee, Wis	1
Rinalds Brothers	Philadelphia, Pa	1
The Sherwin Williams Co	Cleveland, Ohio	3
Toch Brothers	New York City, N. Y	1
Wadsworth, Howland Co	Boston, Mass	1
The A. Wilhelm Co	Reading, Pa	1

The steel plates were contributed by the United States Steel Co.

The actual application of each of the nineteen paints submitted by sixteen different manufacturers, was made both on steel plate panels, three each, at the several spreading rates of 600, 900 and 1200 sq. ft. per gallon of paint, as well as on sections of the bridge proper, where very naturally the spreading rate could not be as absolutely controlled as in the case of the plate panels, but where the natural spreading rate would most probably apply. Neither in the case of the bridge sections was the metal surface as specially prepared as were the plate panels, though undoubtedly the structure was in better condition for field painting than is usually the case, effort being made to clean the structure as well as possible before applying the paint.

Reports have been made from year to year on existing plate-panel conditions—of late years more in detail than was possible at the earlier test periods and attention has been called at various times to certain of the paints on the bridge sections at that time warranting special notice.

The last inspection of the Havre de Grace Bridge was held on Friday, May 3, 1912, with a very full attendance of the inspection committee and a number of other members of Committee D-1, the day being devoted to special examination of the panels under the same schedule of marking used on previous inspections with the customary divisions, namely:

A	Chalking.
B	Checking, Cracking, Alligatoring, Etc.
C	General Surface Conditions.

with the following marking for each:

Excellent	10 to 8
Good	8 to 6
Fair	6 to 4
Poor	4 to 2
Failure	2 to 0

The results of this inspection are given in Table I, showing ratings by nine individual inspectors or pairs of inspectors, for each of the three different rates of spreading of each paint, and in Table II, showing average rating of these same nine inspectors of each paint, covering all rates of spreading. These

TABLE I.—INSPECTION OF GENERAL SURFACE CONDITIONS.

600-SQ-FT. SPREADING RATE.

Paint No.	Aiken and Force.	McNaughton and Thompson.	Voorhees.	Gibboney.	Polk.	Tassin.	White.	Lawrie.	Sabin.	Average.
1	7.0		5.0	4.7	9.0	8.0	8.0	7.0	10.0	7.3
2	6.0		3.0	5.3	0.0	0.0	5.0	5.0	7.0	3.9
3	8.0		7.0	7.0	8.0	7.0	6.5	7.0	10.0	7.5
4	8.0		4.0	7.0	8.5	4.0	5.0	8.0	9.0	6.7
5	9.0		5.0	8.0	9.5	8.0	5.0	7.0	10.0	7.7
6	8.5	McNaughton	6.0	8.0	9.5	8.0	5.0	9.0	10.0	8.0
7	8.0	and	4.0	8.0	7.0	4.0	6.0	7.0	10.0	6.8
8	8.5	Thompson	4.0	8.0	7.0	7.0	7.5	7.0	9.0	7.3
9	7.0	averaged	4.0	4.0	6.0	0.0	5.0	5.0	9.5	5.1
10	8.5	all rates	8.0	10.0	9.5	8.0	7.0	7.0	10.0	8.5
11	9.0	of spreading	8.0	10.0	9.5	8.0	8.0	9.0	10.0	8.9
12	8.5	(See Table II)	8.0	8.3	9.0	6.0	9.0	8.0	10.0	8.3
13	8.0		5.0	6.0	6.9	3.0	6.0	6.0	10.0	6.3
14	9.0		7.0	10.0	9.0	6.0	9.0	8.0	10.0	8.5
15	1.0		0.0	0.0	0.0	0.0	0.0	3.0	5.0	1.1
16	8.5		6.0	8.0	8.0	5.0	7.0	8.0	9.2	7.5
17	8.0		7.0	8.0	8.0	2.0	7.0	7.0	8.8	7.0
18	9.0		7.0	9.0	9.0	5.0	8.0	8.0	10.0	8.1
19	6.0		5.0	5.0	5.0	0.0	6.7	7.0	8.8	5.4

900-SQ-FT. SPREADING RATE.

1	6.0		6.0	5.0	8.0	8.0	7.5	8.0	7.0	7.0
2	2.0		0.0	2.0	2.0	0.0	2.0	0.0	3.0	1.4
3	7.0		7.0	6.0	6.0	4.0	6.0	6.0	9.5	6.4
4	7.0		3.0	6.0	8.0	3.0	4.0	8.0	8.0	5.9
5	8.5		5.0	7.5	9.0	8.0	5.0	8.0	10.0	7.6
6	8.0	McNaughton	6.0	9.0	9.0	8.0	6.0	8.0	10.0	8.0
7	7.5	and	4.0	6.0	4.0	3.0	5.0	6.0	9.0	5.6
8	8.5	Thompson	4.0	6.5	6.0	7.0	6.0	7.0	9.0	6.8
9	5.0	averaged	3.0	2.0	2.0	2.0	4.0	4.0	8.5	3.8
10	7.5	all rates	8.0	10.0	8.5	8.0	7.0	7.0	10.0	8.3
11	9.0	of spreading	8.0	10.0	9.5	8.0	8.0	9.0	10.0	9.0
12	7.5	(See Table II)	7.5	8.0	6.0	3.0	8.0	7.0	10.0	7.1
13	7.0		3.0	4.0	4.0	1.0	4.0	4.0	8.0	4.4
14	8.5		6.5	8.5	8.5	5.0	7.0	7.0	9.5	7.8
15	0.0		0.0	0.0	0.0	0.0	0.0	2.0	4.0	0.8
16	8.0		5.0	8.0	6.0	4.0	6.0	7.0	9.2	6.7
17	7.0		6.0	4.5	7.0	3.0	5.0	6.0	7.5	5.8
18	8.0		6.0	9.0	8.5	6.0	8.0	7.0	9.5	7.8
19	7.0		6.0	4.0	8.0	0.0	7.0	7.0	8.8	6.7

1200-SQ-FT. SPREADING RATE.

1	6.5		6.0	4.7	8.0	6.0	7.0	8.0	7.0	6.7
2	0.0		0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0
3	5.0		3.0	2.0	4.0	2.0	4.0	5.0	8.0	4.1
4	6.0		3.0	4.0	6.0	0.0	4.0	8.0	7.0	4.8
5	6.5		5.0	7.0	7.0	6.0	4.0	8.0	9.0	6.6
6	7.0	McNaughton	6.0	9.0	9.0	8.0	6.0	8.0	10.0	7.9
7	2.0	and	2.0	2.0	2.0	0.0	2.0	4.0	5.0	2.4
8	8.0	Thompson	4.0	5.0	4.0	6.0	6.0	7.0	8.0	6.0
9	0.0	averaged	0.0	0.0	0.0	0.0	2.0	2.0	4.0	1.0
10	7.0	all rates	7.0	10.0	8.0	8.0	7.0	7.0	10.0	8.0
11	8.0	of spreading	8.0	10.0	9.5	8.0	8.0	9.0	10.0	8.8
12	5.0	(See Table II)	4.0	6.0	4.0	2.0	6.0	6.0	8.8	5.2
13	4.0		2.0	4.0	0.0	0.0	3.0	5.0	6.0	3.0
14	7.5		6.0	8.0	8.0	4.0	6.0	6.0	9.5	7.0
15	2.0		1.0	0.0	0.0	0.0	1.0	4.0	6.5	1.8
16	6.0		4.0	7.0	4.0	3.0	5.0	5.0	8.0	5.2
17	7.0		6.0	5.0	7.0	7.0	6.0	7.0	7.0	6.8
18	7.0		6.0	8.0	7.0	5.0	6.0	5.0	8.0	6.5
19	7.0		6.0	4.0	7.0	0.0	5.0	7.0	8.0	5.5

TABLE II.—INSPECTION OF GENERAL SURFACE CONDITIONS.

COMPILED AVERAGE OF ALL RATES—600, 900, 1200 SQ. FT.

Paint No.	Aiken and Force.	McNaughton and Thompson.	Voorhees.	Gibboney.	Polk.	Tassin.	White.	Lawrie.	Sabin.	Average.
1	6.5	7.0	5.7	4.8	8.3	7.3	7.5	7.7	8.0	7.0
2	2.7	0.0	1.0	2.4	0.7	0.0	3.0	1.7	3.3	1.6
3	6.7	8.0	5.7	5.0	6.0	4.3	5.5	6.0	9.2	6.3
4	7.0	6.0	3.3	5.7	7.5	2.3	4.3	8.0	8.0	5.8
5	8.0	9.0	5.0	7.5	8.3	7.3	4.7	7.7	9.7	7.3
6	7.8	9.0	6.0	8.7	9.2	8.0	5.7	8.3	10.0	8.0
7	5.7	3.3	3.3	5.3	4.3	2.3	4.3	5.7	8.0	5.1
8	8.3	8.0	4.0	6.5	5.7	6.7	6.5	7.0	8.7	6.7
9	4.0	5.0	2.3	2.0	2.7	0.7	3.7	3.7	7.3	3.5
10	7.7	9.0	7.8	10.0	8.7	8.0	7.0	7.0	10.0	8.3
11	8.7	9.0	8.0	10.0	9.5	8.0	8.0	9.0	10.0	8.9
12	7.0	7.0	6.5	7.4	6.3	3.7	7.7	7.0	9.6	6.9
13	6.7	5.0	3.3	4.7	3.3	1.3	4.3	5.0	8.0	4.6
14	8.3	8.0	6.5	8.8	8.5	5.0	7.3	7.0	9.7	7.7
15	1.0	0.0	0.3	0.0	0.0	0.0	0.3	3.0	5.2	1.2
16	7.5	7.0	5.0	7.8	6.0	4.0	6.0	6.7	8.7	6.5
17	7.3	6.0	6.3	5.8	7.3	4.0	6.0	6.7	7.8	6.5
18	8.0	8.0	6.3	8.7	8.2	5.3	7.3	6.7	9.2	7.5
19	6.7	7.0	5.7	4.3	6.7	0.0	6.2	7.0	8.5	5.9

TABLE III.—CLASSIFICATION FROM TABLES I AND II.

Paint No.	Panel Spreading Rate, sq. ft. per gal.			Average.	Bridge Sections.
	600	900	1200		
1	II	II	III	II	II
2	V	V	V	V	V
3	II	III	V	III	II
4	III	IV	V	IV	IV
5	II	II	III	II	II
6	I	I	I	I	I
7	III	IV	V	IV	IV
8	II	III	III	III	II
9	IV	V	V	V	IV
10	I	I	I	I	I
11	I	I	I	I	I
12	I	II	IV	III	II
13	III	V	V	V	IV
14	I	II	II	II	II
15	V	V	V	V	V
16	II	III	IV	III	II
17	II	IV	III	III	II
18	I	II	III	II	II
19	IV	III	IV	IV	IV

DESCRIPTION OF CLASSES.

Class.	Averaging.	600 sq. ft.	900 sq. ft.	1200 sq. ft.	Description.
I	8–9	8.4	8.4	8.2	Quite excellent
II	7–8	7.4	7.5	7.0	Quite good
III	6–7	6.6	6.6	6.1	Good
IV	5–6	5.3	5.8	5.3	Fair
V	below 5	...	...	...	Poor or failed

TABLE IV.—SUMMARY FROM TABLE III, SHOWING THE PAINTS FALLING IN THE VARIOUS CLASSES.

Class.	Panel Spreading Rate, sq. ft. per gal.			Average.	Bridge Sections.
	600	900	1200		
I	6, 10, 11, 12, 14, 18.	6, 10, 11.	6, 10, 11.	6, 10, 11.	6, 10, 11.
II	1, 3, 5, 8, 16, 17.	1, 5, 12, 14, 18.	14.	1, 5, 14, 18.	1, 3, 5, 8, 12, 14, 16, 17, 18.
III	4, 7, 13.	3, 8, 16, 19.	1, 5, 8, 17, 18.	3, 8, 12, 16, 17.	.....
IV	9, 19.	4, 7, 17.	12, 16, 19.	4, 7, 19.	4, 7, 9, 13, 19.
V	2, 15.	2, 9, 13, 15.	2, 3, 4, 7, 9, 13, 15.	2, 9, 13, 15.	2, 15.

tables cover only division C (general surface conditions) such being considered at this time the most important point as defining the protective value of the paints. Table III shows a classification of the data in Tables I and II. Table IV is a summary prepared from Table III.

In analyzing these "general surface condition" averages of the several rates of spreading, the results have been divided arbitrarily into five classes, as follows:

Class I, including paints with average markings between 8.0 and 9.0; quite excellent.

Class II, including paints with average markings between 7.0 and 8.0; quite good.

Class III, including paints with average markings between 6.0 and 7.0; good.

Class IV, including paints with average markings between 5.0 and 6.0; fair.

Class V, including paints with average markings below 5.0; poor or failed.

We find under the 600-sq-ft. rate of spreading:

Six paints (Nos. 6, 10, 11, 12, 14 and 18) with an average of 8.4, designated as quite excellent in Class I;

Six paints (Nos. 1, 3, 5, 8, 16 and 17) with an average of 7.4, designated as quite good in Class II;

Three paints (Nos. 4, 7 and 13) with an average of 6.6, designated as good in Class III;

Two paints (Nos. 9 and 19) with an average of 5.3, designated as fair in Class IV; and
Two paints (Nos. 2 and 15) which have failed.

We find under the 900-sq-ft. rate of spreading:

Three paints (Nos. 6, 10 and 11) with an average of 8.4, designated as quite excellent in Class I;
Five paints (Nos. 1, 5, 12, 14 and 18) with an average of 7.5, designated as quite good in Class II;
Four paints (Nos. 3, 8, 16 and 19) with an average of 6.6, designated as good in Class III;
Three paints (Nos. 4, 7 and 17) with an average of 5.8, designated as fair in Class IV; and
Four paints (Nos. 2, 9, 13 and 15) which are poor (Nos. 9 and 13) or have failed (Nos. 2 and 15)—these last two being those marked as failing under the 600-sq-ft. spreading rate.

We find under the 1200-sq-ft. rate of spreading:

Three paints (Nos. 6, 10 and 11) with an average of 8.2, designated as quite excellent in Class I;
One paint (No. 14) with an average of 7.0, designated as quite good in Class II;
Five paints (Nos. 1, 5, 8, 17 and 18) with an average of 6.1, designated as good in Class III;
Three paints (Nos. 12, 16 and 19) with an average of 5.3, designated as fair in Class IV; and
Seven paints (Nos. 2, 3, 4, 7, 9, 13 and 15) which are marked poor (two), or to have failed (five). Two of these failed on previous spreading rates, two are noted in Class III and one in Class IV, even under the 600-sq-ft. spreading rate.

Note that the three paints in Class I under the 900 and 1200-sq-ft. rate of spreading are identical with three of the six in this same class under the 600-sq-ft. rate. Note also that the other three in Class I under the 600-sq-ft. rate drop into Class II under the 900-sq-ft. rate, and that only one of these barely maintains its standing in this class under the 1200-sq-ft. rate, the other two dropping, one into Class III and the other into Class IV.

Note that of the six paints originally in Class II under the 600-sq-ft. rate of spreading, only two maintain this standing

under the 900-sq-ft. rate, and none maintain such standing under the 1200-sq-ft. rate.

Note that of the three paints originally in Class III under the 600-sq-ft. rate of spreading, none maintains this standing at the 900-sq-ft. rate and all disappear as poor or failures under the 1200-sq-ft. rate.

Note that of the two paints originally in Class IV under the 600-sq-ft. rate of spreading, one has no standing in either the 900 or 1200-sq-ft. rate, but the other ascends to Class III under the 900-sq-ft. rate, which is rather anomalous, but tends to show that its natural spreading rate is apparently 900 sq. ft. per gallon and not 600 sq. ft. as the bulk of the other paints show, although it may be noted here that the three paints which appear in Class I under all three rates of spreading are apparently equally without any distinctive natural spreading rate.

The inspection of the bridge proper, from which conclusions are hereafter drawn relative to the protective value of the different paints thereon, was made Friday, May 24, by the Chairman, assisted by Messrs. Anderson Polk and Wirt Tassin, both of the inspection committee.

Three paints (Nos. 6, 10 and 11) in Class I, under each of the separate spreading rates, may each well be designated as excellent on the bridge sections, though they vary slightly in degree of merit. What differentiates these paints from all others under observation is the fact that while all the other paints except one furnish their best protection, such as it is, under the 600-sq-ft. rate of spreading and are generally markedly less effective under the thinner film rate, these three show such slight variation under different rates of application as to appear equally protective under either. Further, these three paints show more concordant results between the test panels and the bridge sections than any others.

This is not to be interpreted as meaning that there is no evidence of failure of these paints on the bridge proper, for there is some deterioration taking place; but the protection as a whole is to-day excellent and concordant with the panel observations as being very nearly identical in showing.

Nine paints, three (Nos. 12, 14 and 18) being of Class I, under the 600-sq-ft. spreading rate—referred to in our pre-

vious analysis of the panel inspection as falling into the next class under the 900-sq-ft. rate—and six paints (Nos. 1, 3, 5, 8, 16 and 17), originally of Class II, under the 600-sq-ft. rate, deserve possibly a higher rating than Class II on the bridge proper, since the protection furnished, while failing here and there as have practically all the paints in spots,—for which there may be more or less local explanation,—is generally effective. These nine paints, while not in a class with the three paints specifically referred to above as being in a class by themselves, show upon the bridge proper much better protection generally than on their corresponding best panels, and may be designated on the bridge as very good—certainly superior to the quite good of the panels. In some instances, however, notably paint No. 1, failure may occur at any time, in our opinion, despite the present apparent protection being furnished. Paint No. 1 is apparently in much better condition than close examination shows it to be in reality.

Of the remaining seven paints, paint No. 2, while markedly better than its panels, which have practically entirely failed even at the 600-sq-ft. spreading rate, should be eliminated.

Paint No. 4 needs attention, as it is only furnishing protection about equal to its best panel showing, which is marked good; but the paint on the bridge section, we think, might well be replaced.

Paint No. 7, while appearing in a very low class under the 900-sq-ft. spreading rate and as failed under the 1200-sq-ft. rate in the panels, is in as good condition on the bridge proper as in its panels on the 600-sq-ft. rate, but we think that the life of the paint has about ended on its bridge section.

Paint No. 9 on the bridge proper needs replacement, though it is fully equal to its best panel, which is only fair.

Paint No. 13 on the bridge proper, though better than its best panels, should be replaced.

Paint No. 15, though better than its panels, should be replaced.

Paint No. 19 needs replacing, though only in part at present, being in much better condition than its best panel, which while of low class rating has not been marked as a failure.

The analyses of all paints were given originally in Vol. VIII of the Proceedings (1908), and can be located therefrom by their numbers as given in this report.[1]

As originally contemplated, an attempt has been made to classify the paints from their compositions, but it has been found impracticable so to do.

At our request the Pennsylvania Railroad Co. agreed to having inspection made of this section of the Havre de Grace bridge and the panel tests by themselves and the representatives of other railroads. The reports of these inspections are appended hereto, together with a tabular comparison of these reports and those obtained by our own inspectors.

Respectfully submitted on behalf of the sub-committee,

W. A. AIKEN,
Chairman.

[1] Pp. 173 ff. of Vol. VIII, in which the panel numbers correspond to the paint numbers given herewith.

APPENDIX.

REPORTS OF INSPECTION OF HAVRE DE GRACE BRIDGE BY VARIOUS RAILROADS.

PENNSYLVANIA RAILROAD COMPANY.

PHILADELPHIA, April 10, 1913.

MR. W. A. AIKEN,
Chairman, Sub-Committee B, Committee D-1,
American Society for Testing Materials.

Dear Sir:

Referring to our conversation of recent date, I have to advise you that my assistant, Mr. Robert Farnham, Jr., made an examination of the painting of the plates and on the bridge truss proper at the Havre de Grace Bridge, on March 6 last, in company with Mr. Samuel Tobias Wagner, Assistant Engineer, Philadelphia and Reading Railway Co., and reports as follows:

The painting on the plates and trusses were divided into five classes as follows: Excellent, Good, Fair, Poor, and Failure.

For the purpose of rating, the paint on the plates marked "1200 sq. ft." is called A; plates marked "900 sq. ft.," B; plates marked "600 sq. ft.," C, and bridge trusses D.

After a careful examination, I have rated the paints as follows:

Paint No.	A	B	C	D
1	Poor	Poor	Fair	Good
2	Failure	Failure	Poor	Fair
3	Poor	Fair	Good	Fair
4	Poor	Poor	Fair	Poor
5	Good	Excellent	Excellent	Excellent
6	Good	Excellent	Excellent	Excellent
7	Failure	Good	Excellent	Good
8	Poor	Fair	Fair	Fair
9	Failure	Poor	Good	Fair
10	Good	Excellent	Excellent	Good to Excellent
11	Good	Good	Excellent	Good
12	Good	Good	Excellent	Fair to Good
13	Failure to Poor	Poor	Good	Fair
14	Fair	Fair	Fair to Good	Fair
15	Poor	Failure	Failure	Poor
16	Poor	Fair	Fair	Good
17	Fair	Fair	Good	Good
18	Fair	Good	Excellent	Good
19	Fair	Fair	Fair	Fair

Yours truly,

H. R. LEONARD,
Engineer of Bridges.

THE BALTIMORE AND OHIO RAILROAD COMPANY.

BALTIMORE, March 29, 1913.

MR. W. A. AIKEN,
Chairman, Sub-Committee B, Committee D-1,
American Society for Testing Materials.

Dear Sir:

Referring to yours of March 1, requesting that inspection be made of the preservative coatings on the Pennsylvania Railroad Bridge at Havre de Grace, I attach hereto copy of report from Assistant-Engineer-of-Bridges Edwards to Engineer-of-Bridges Bouton, which I trust will serve your purpose.

If consistent, would appreciate it if you will let me know the names of the manufacturers of the paints indicated by numbers, and also the trade names under which the paints are sold.

Yours truly,

F. L. STUART,
Chief Engineer.

March 25, 1913.

MR. W. S. BOUTON,
Engineer of Bridges.

Dear Sir:

In compliance with your instructions, I made an examination on the 24th instant of the condition of the paint on the test sheets, placed on the Pennsylvania Railroad bridge at Havre de Grace by Committee D-1 of the American Society for Testing Materials. In making this inspection I graded each of the test sheets as to general condition, using the standard system of numbering from 0 to 10, which has been adopted by the Committee in their previous reports on these tests. The following table shows the average of these gradings for each of the three rates of application, and also the general average for each paint.

Paint No.	Average Condition, Sheets I.	Average Condition, Sheets II.	Average Condition, Sheets III.	General Average.	Bridge.
1	7.0	7.3	7.2	7.1	7.1
2	0.0	0.5	3.2	1.3	3.2
3	6.8	8.3	8.5	7.8	7.8
4	6.5	7.3	7.2	6.9	3.5
5	8.3	9.3	9.4	9.0	9.0
6	8.9	9.2	8.6	8.9	8.9
7	3.2	7.2	8.8	6.3	6.3
8	7.5	8.2	8.9	8.0	8.0
9	0.2	3.5	4.7	2.7	2.7
10	9.0	9.5	9.5	9.3	9.3
11	9.5	9.5	9.5	9.5	9.5
12	7.8	8.8	8.8	8.4	8.4
13	2.3	4.7	8.2	5.1	8.2
14	8.0	8.5	9.0	8.5	8.5
15	4.3	0.7	0.8	2.1	2.1
16	6.1	8.6	8.8	7.7	7.5
17	7.3	7.0	7.5	7.3	7.3
18	6.8	7.0	8.2	7.4	7.4
19	7.3	7.3	7.1	7.1	7.0

The general condition of the paint on the bridge is about the same as that on the test sheets, for Paints Nos. 1, 3, 6, 10, 12, 14, 17 and 18.

For Paint No. 2 the general condition on the bridge is about the same as that represented by Sheets III, and the rust is showing through the paint very generally.

The general condition of Paint No. 4 on the bridge is quite poor, being only about 50 per cent as good as shown by the test sheets.

Paint No. 5 is in slightly better average condition on the bridge than on the test sheets, but the correspondence between the two is very close.

The condition of Paint No. 7 on the bridge is very uneven, being excellent in places and almost a complete failure elsewhere. The general average is about the same as on the test sheets.

The condition of Paint No. 8 on the bridge is not quite so good as that on the test sheets. On horizontal surfaces the paint is practically dead and the metal exposed and rusted.

Paint No. 9 is entirely gone from the bridge in places, but is in fair condition on protected surfaces. The test sheets indicate that this paint is just about at the point of complete failure where exposed.

The condition of Paint No. 11 on the bridge, while excellent, is not quite so good as shown on the test sheets.

The condition of Paint No. 13 on the bridge will average about the same as on Sheets III, and the better one of Sheets II. There is no considerable area where the conditions are as bad as indicated by Sheets I.

The condition of Paint No. 15 on the bridge is poor, but is considerably better than that shown on the test sheets, except over limited areas.

The condition of Paints Nos. 16 and 19 on the bridge is slightly worse than that shown on the test sheets.

Yours truly,

W. R. EDWARDS.
Asst. Engineer of Bridges.

PHILADELPHIA AND READING RAILWAY COMPANY.

PHILADELPHIA, March 7, 1913.

MR. W. A. AIKEN,
Chairman, Sub-Committee B, Committee D-1,
American Society for Testing Materials.

Dear Sir:

Referring to our recent interview in which you asked me to have someone in this Company examine the paints on the Susquehanna River Bridge at Havre de Grace, Pennsylvania Railroad, in connection with the work of the American Society for Testing Materials, I beg to advise you that I turned this matter over to Assistant-Engineer Wagner for his attention, and he advises me that he has been in consultation with you and that you asked him to prepare a report covering this matter.

I am handing you this report herewith, and trust that you will find it satisfactory.

Yours truly,

W. HUNTER,
Chief Engineer.

March 7, 1913.

MR. W. A. AIKEN,
Chairman, Sub-Committee B, Committee D-1,
American Society for Testing Materials.

Dear Sir:

Complying with your recent request, I visited the Susquehanna River Bridge of the Pennsylvania Railroad, at Havre de Grace, yesterday, accompanied by Mr. Robert Farnham, Jr., Assistant Engineer, Pennsylvania Railroad Co., and made an examination of the painting of the panels of plates and the paint on the bridge trusses proper.

Separate notice was taken of the following specimens under each number of the paint as applied:

A. Panel (plate) marked 1200 sq. ft.
B. Panel (plate) marked 900 "
C. Panel (plate) marked 600 "
D. Bridge trusses.

As to the character of the paint at the present time, I have endeavored to describe it under the following headings:

Excellent, Good, Fair, Poor, and Failure.

According to my best judgment, the ratings would be as follows:

Paint No.	A	B	C	D
1	Poor	Poor	Fair	Good
2	Failure	Failure	Poor	Fair
3	Poor	Fair	Good	Fair
4	Poor	Poor	Fair	Poor
5	Good	Good	Excellent	Excellent
6	Good	Excellent	Excellent	Excellent
7	Failure	Good	Excellent	Good
8	Poor	Fair	Fair	Fair
9	Failure	Poor	Good	Fair
10	Good	Good	Excellent	Good
11	Good	Good	Excellent	Good
12	Good	Good	Excellent	Fairly Good
13	Poor to Failure	Fair	Good	Fair
14	Fair	Fair	Fair	Fair
15	Poor	Failure	Failure	Poor
16	Poor	Fair	Fair	Good
17	Fair	Fair	Good	Good
18	Fair	Good	Excellent	Good
19	Fair	Fair	Fair	Fair

The records under heads A, B and C covered the average of three plates of A and C, respectively, and but two plates of B. One plate of B of each paint had been removed from the bridge.

Respectfully submitted,

SAMUEL TOBIAS WAGNER,
Assistant Engineer.

NEW YORK CENTRAL AND HUDSON RIVER RAILROAD COMPANY.

NEW YORK, April 5, 1913.

MR. W. A. AIKEN,
Chairman, Sub-Committee B, Committee D-1,
American Society for Testing Materials.

Dear Sir:

On the 1st instant we made the examination that you requested of the paint tests on the Havre de Grace bridge.

The following schedule gives the averages of our marks as representing the general surface conditions; these apply to the test plates only:

Paint No.	Spreading Rate, sq. ft. per gal.			Average.
	1200	900	600	
1	5.0	5.0	5.5	5.2
2	1.5	2.5	4.0	2.7
3	5.5	8.0	8.0	7.2
4	5.0	6.0	7.0	6.0
5	6.0	7.25	8.25	7.2
6	7.0	8.0	8.0	7.7
7	3.0	5.0	8.0	5.3
8	4.5	5.75	7.75	6.0
9	2.0	3.5	5.0	3.5
10	5.0	8.0	9.25	7.4
11	9.0	9.0	9.0	9.0
12	6.0	7.75	8.5	7.4
13	3.0	4.5	7.0	4.8
14	5.5	7.0	8.5	7.0
15	2.25	2.0	2.5	2.3
16	3.75	6.0	6.5	5.4
17	4.5	5.0	7.0	5.5
18	5.0	6.0	7.25	6.1
19	5.5	5.5	5.5	5.5

The marks are on the basis that you described in your letter of the 19th ult., as follows:

10 to 8, excellent; 8 to 6, good; 6 to 4, fair; 4 to 2, poor; and 2 to 0, failed.

There was a high wind blowing when we made our examination, and we noticed that some of the fastenings were broken or loosened, so there seemed to be some danger of some of the plates being lost if these fastenings are not repaired soon.

We noticed that a number of the plates were missing, usually those of the 900-sq-ft. spreading rate, and not more than one of the three plates in each case. These, we understand from information received at the Pennsylvania Railroad Company Supervisor's office adjacent to the bridge, had been removed intentionally.

Yours very truly,

A. W. CARPENTER,
Engineer of Structures, Ext. Zone.
J. L. HOLST,
Engineer of Structures, Elec. Zone.

April 9, 1913.

MR. W. A. AIKEN,
Chairman, Sub-Committee B, Committee D-1,
American Society for Testing Materials.

Dear Sir:

Acknowledging receipt of yours of April 8, in the matter of test plates on the Havre de Grace Bridge:

Mr. Carpenter and I will give you a statement some time next week covering our opinion of the relative merits of the paints as applied to the plates and as applied to the structure.

Yours very truly,

J. L. HOLST,
Engineer of Structures.

April 16, 1913.

MR. W. A. AIKEN,
Chairman, Sub-Committee B, Committee D-1,
American Society for Testing Materials.

Dear Sir:

Conforming to yours of April 8, we have the following statement to make, concerning condition of paint films on the Havre de Grace Bridge as compared with the films on experimental plates.

Generally speaking the films on the bridge are superior to same on plates, especially if comparison is made between plates and vertical surfaces on the bridge. The horizontal surfaces on the bridge are in general in worse condition than the vertical surfaces. The films on the vertical surfaces of posts having the same exposure as the plates were, in most cases, distinctly superior to the films on the plates.

Detail observations on each group are as follows:

Group 1.—Bridge films better than plate films. Do not differ much, however, from films on "600" plates.

Group 2.—Bridge films distinctly better than plate films.

Group 3.—Plate films better than bridge films. The films on the bridge were, in general, in slightly worse condition than films on "1200" plates. Poor condition of paint films on bridge especially noticeable on horizontal surfaces and bottom chord.

Group 4.—Bridge films considerably inferior to plate films, especially on horizontal surfaces and bottom chord.

Group 5.—Bridge films better than plate films. Slightly better than the "600" plates, especially superior on face of post having same exposure as plates.

Group 6.—Bridge films slightly inferior to plate films. Mainly due to relatively poor condition of paint films on horizontal surfaces.

Group 7.—Bridge films better than plate films. Bridge films compare favorably with films on "600" plates.

Group 8.—Bridge films inferior to plate films. Bridge films compare with films on "1200" plates. Comparative inferiority of bridge films due largely to poor condition of films on horizontal surfaces.

Group 9.—Bridge films in approximately same condition as films on "900" plates and are considered superior to films on "1200" plates, but inferior to films on "600" plates. Horizontal surfaces on the bridge are in very poor condition. Vertical surfaces not so bad.

Group 10.—Bridge films superior to plate films. The films on the "600" plates are the best of the plate films and are considered slightly inferior to the bridge films. Film on the bridge is thin, is checking and chalking. Notwithstanding this there seems to be at present first-class protection.

Group 11.—Bridge films in approximately same condition as plate films. Material is chalking somewhat but affords first class protection.

Group 12.—Bridge films superior to films on "1200" plates and inferior to films on "600" plates. In approximately same condition as films on "900" plates.

Group 13.—Bridge films better than plate films. The best plate films are on the "600" plates and the bridge films appear superior thereto. This is especially true on vertical surfaces.

Group 14.—Bridge films slightly inferior to films on "600" plates and superior to films on "900" and "1200" plates. The comparison in this case was difficult by reason of the fact that the material did not seem to act the same on the bridge as on the plates. On the plates pitting was distinctly noticeable and there seemed to be no scaling, whereas on the bridge paint had scaled off in a number of instances over areas of 2 or 3 sq. in. and there was relatively a small amount of pitting. If the scaling on the bridge is attributed to faulty execution and disregarded, the films on the bridge are superior to the plate films.

Group 15.—Bridge films better than plate films. They are only slightly superior, however, to films on the "1200" plates.

Group 16.—Bridge films better than plate films. Films on "600" plates are the best of the plate films and films on the bridge are slightly superior to these.

Group 17.—Bridge films are in about the same condition as films on "900" and "1200" plates and are inferior to films on "600" plates.

Group 18.—Bridge films better than plate films especially on the vertical surfaces. Would rate bridge films as slightly better than films on "600" plates.

Group 19.—Bridge films better than plate films. Bridge films are especially superior on vertical surfaces.

In making the above comparisons we used the paint on that portion of the bridge which was accessible from the temporary platform as represent-

ing the general condition of paint on the bridge. Paint on top chord and floor system was not examined.

Yours very truly,

J. L. HOLST,
Engineer of Structures, Elec. Zone.
A. W. CARPENTER,
Engineer of Structures, Ext. Zone.

NORFOLK AND WESTERN RAILWAY COMPANY.

ROANOKE, VA., April 17, 1913.

MR. W. A. AIKEN,
Chairman, Sub-Committee B, Committee D-1,
American Society for Testing Materials.

Dear Sir:

In accordance with your letter of March 5, I inspected the various paints on test on the Havre de Grace Bridge in company with Mr. J. H. Gibboney on March 26. I returned to Roanoke on March 27, and almost immediately after my return received notice of high water in Ohio which called me to the western end of our line where we were cut off by high water for two weeks, and it was impossible for me to make a report sooner, as I only returned to my office, where I had left all my data, yesterday morning. I very much regret this delay and hope you will excuse the same.

I found it a very difficult matter to make an entirely just rating of the various paints, and in order to aid my judgment in the matter I selected five different points in the various panels and gave each panel a rating for each point, after which I took a general average of the five ratings as being the rating for the panel. I have assumed that any paint which will prevent any marked corrosion *under the conditions of service* at this point for a period of six years should be rated as good, even though the panel at the end of the six years requires re-painting.

Following the rating laid down in your letter to Mr. Churchill of March 1, that is, 8 to 10 being excellent, 6 to 8 being good, 4 to 6 being fair, 2 to 4 being poor and 0 to 2 being failed, I rate these paints as follows:

Paint No.	Rating.	Paint No.	Rating.	Paint No.	Rating.	Paint No.	Rating.
1	5.9	6	7.9	11	7.5	16	7.6
2	5.6	7	6.9	12	7.9	17	6.0
3	5.6	8	5.5	13	6.5	18	7.0
4	5.1	9	6.5	14	7.1	19	6.5
5	7.9	10	7.3	15	4.5	.....	.....

Yours truly,

J. E. CRAWFORD,
Bridge Engineer.

COMPARISONS OF RATINGS BY SUB-COMMITTEE B AND OUTSIDE INSPECTIONS OF PAINTS, ON BRIDGE SECTIONS, HAVRE DE GRACE BRIDGE, MARCH, 1913—ONE YEAR APART.

Description.	Sub-Committee B. 1912.	Pennsylvania R. R. Co. 1913.	Baltimore & Ohio R. R. Co. 1913.	Philadelphia & Reading Ry. Co. 1913.	New York Central & Hudson River R. R. Co. 1913.	Norfolk & Western Ry. Co. 1913.
Excellent or Quite Good	6	6	6	6	6	6
	10	10	10	10	10	10
	3	..	3	..	3	..
	11	11	11	11	11	11
	1	1	1	1	..	..
	5	5	5	5	5	5
	12	12	12	12	12	12
	14	..	14	..	14	14
	16	16	16	16	..	16
	17	17	17	17	..	17
	18	18	18	18	..	18
	..	7	..	7	..	7
	..	..	13	..	..	13
	..	..	19	..	..	19
	..	..	..	..	..	9
	..	..	..	..	4	..
Fair	4	..	..	..	..	4
	7	..	7	..	7	..
	9	9	..	9	..	..
	13	13	..	13	13	..
	19	19	..	19	19	..
	..	14	..	14	..	..
	..	8	8	8	8	8
	..	3	..	3	..	3
	..	2	..	2	..	2
	..	..	..	..	16	..
	..	..	..	..	17	..
	..	..	..	..	18	..
	..	..	..	..	1	..
	..	..	..	..	..	15
Poor	..	4	4	4	..	..
	..	15	..	15	15	..
	..	..	9	..	9	..
	..	..	..	..	2	..
Failed	2	..	2	..	..	..
	15	..	15	..	..	..

REPORT OF SUB-COMMITTEE C ON PAINT VEHICLES.

After the completion of a series of preliminary experiments made to determine whether semi-drying oils could be treated so as to be improved in their drying value, a meeting of Sub-Committee C was held in Brooklyn, N. Y., on March 3, 1912. The meeting was attended by Messrs. Thompson, Pickard, Sabin, Toch, Schaeffer, Lane, Ingalls, Voorhees, Nemzek, Boughton, White, Rogers, Lawrie and Gardner.

The committee decided at this meeting that soya and tung oils, on account of their growing use, should be the subject of the year's investigations, with a view to working out reliable tests for determining their value and purity.

TESTS ON SOYA BEAN OILS.

Members of the committee pointed out that soya oils, crushed from various types of beans, might differ in their drying value and general utility as paint oils, and that it would be advisable to develop some quick tests to determine the suitability of raw soya oils as they are found in the market. Mr. Toch stated that his purchases of soya oil were always subject to a heat test conducted in his laboratory, which determined in a short time whether the oil was suitable for use as a paint oil. The committee decided to include such a test in the investigation work on soya oils. A number of samples of soya oils for the tests were obtained from different brokers. These oils were of commercial grade and no data was obtainable as to their purity or source. The samples were labeled and numbered and then submitted to each member of the committee, together with the following instructions as to tests to be made with the oils:

1. *Analytical Constants to be Determined:*

   (*a*) Specific gravity at $\frac{15°.5}{15°.5}$ C.;

   (*b*) Saponification number;

   (*c*) Iodine number (Hanus);

   (*d*) Acid number.

2. *Heat Test.*—Heat 2 oz. of the oil at 450° F. in a glass receptacle until bleaching is noticed. Then blow a slow current of dry air through the oil until the specific gravity has increased to 0.950. This may require a period of 7 hr. The blowing should be conducted at a temperature between 300° and 370° F. The oil should become light and fairly rapid drying.

3. *Drying Test.*—Place on a table a white sheet of paper 10 cm. square (100 sq. cm. in area). Upon this piece of paper place a weighed and marked piece of ordinary clear window glass about 15 cm. square. On the white area outlined on the paper below the glass, drop about 10 drops of the oil to be tested (approximately 200 mg.). Brush out the oil with a clean camel's-hair brush, so that it will cover the white area. Reweigh the glass to determine the amount of oil thereon. The plate may then be lifted by the edge which is uncoated and placed in a convenient place for drying. The number of hours required for the oil to dry to a firm film should be noted. The change in weight should be determined by reweighing the plate at the end of the third day.

A practical factory test of one of the samples is being conducted by Mr. White.

TESTS ON TUNG OILS.

On account of the adulteration of some shipments of raw Chinese wood oil which have been received in this country, the question arose during the committee meeting as to whether chemical constants or practical heat tests would be more satisfactory in determining the value of this oil. Practical kettle tests in the factory on large amounts of oil will determine whether the oil is suitable for varnish purposes, and such a test is no doubt an important one to make. The general opinion of the committee was to the effect that a laboratory heat test would give equally as much information as a larger test. It was felt that if a series of laboratory heat tests should be made upon a number of samples of tung oil, and the analytical constants of these samples could be determined at the same time, much valuable information would be afforded regarding the composition of such oils, and that such information might be used as the basis for standardization of the analytical constants of tung oils. A series of tung oils was therefore secured from various brokers. No data were obtainable as to their purity or exact source. Labeled and numbered samples were submitted to

each member of the committee, with instructions to make the following tests:

1. *Analytical Constants to be Determined:*

(*a*) Specific gravity at $\frac{15°.5}{15°.5}$ C.;

(*b*) Saponification number;

(*c*) Iodine number (Hübl 18 hr.);

(*d*) Acid number.

2. *Heat Test.*—Heat 2 oz. of the oil at 420° F. for 20 min. in a glass beaker of 150 cc. capacity. The oil should polymerize. Raise the temperature to 520° F. and hold for 10 min. The oil should be converted into a spongy, semi-solid mass. Test the mass with a knife to see whether it will cut clean without adhering to the knife.

RESULTS OF TESTS.

The results of the tests submitted by members of the committee are given in Tables III–XXII in Appendix I to this report (pages 355–364).

Soya Bean Oils.—In the determination of the analytical constants of soya oil, results which agree very closely were obtained by nearly all of the observers, which would indicate that soya oils have a fairly well defined chemical constitution, even though they may be pressed from various seeds grown in different states. The average constants are given in Table I.

TABLE I.—AVERAGE CONSTANTS OF 9 SAMPLES[1] OF RAW SOYA BEAN OIL AS TAKEN FROM THE RESULTS OF NINE OBSERVERS.

Specific gravity	0.9247
Saponification number	192.0
Iodine number	134.5
Acid number	2.14

The heat tests to which the soya oils were subjected gave interesting results, but did not in any case seem to increase the drying value of the oils. It is fairly well established by the tests that most soya oils will bleach under the heat treatment, but the committee is not prepared to state that those oils which do not bleach are unfit for use as paint oils.

[1] Soya oil No. 3 omitted for reason stated in note to Table V, Appendix I. Soya oil No. 6 (Blown) omitted from averages.

In the drying tests, as a rule, rapid initial setting was observed with the blown oils, but they remained tacky for a long period of time. Unfortunately, the drying tests on the blown-oil samples gave widely varying results. Toch states that the abnormally high results obtained in his experiments were probably due to the deposition of extraneous matter on the films, the atmosphere where the tests were made being that of a manufacturing city. In another instance the operator flowed the oil upon the plates in thick films, rather than brushing the oil out as outlined in the instructions for the tests. The failure of the various members to obtain concordant results in these drying tests would indicate that the method used is not satisfactory in its present form. Nearly all observers noted a peculiar crawling of the films, which would indicate that raw soya oil is not well adapted to use as a paint oil, unless treated with a drier.

Tung Oils.—The general uniformity of analytical results, except in the case of the McIlhiney test, as shown in the reports of the observers, would indicate that tung oil has definite constants of slight variation. That such constants are of value in determining the purity of tung oil, there can be no doubt.

TABLE II.—AVERAGE CONSTANTS OF 8 SAMPLES OF RAW TUNG OIL AS TAKEN FROM THE RESULTS OF NINE OBSERVERS.

Specific gravity	0.9407
Saponification number	192.9
Iodine number	168.9
Acid number	5.69

The purity and value of tung oil should not be judged, however, entirely from the constants of the oil, as the heat test has come to be generally acknowledged as a most valuable asset in determining its purity. The temperature at which the heat test is made is a most important factor for consideration. In the above tests the oil was shown to remain in a liquid condition at 420° F. without apparent polymerization. As a matter of fact, changes of a profound nature occur at such temperature, but they are not apparent until the oil has been cooled and examined chemically and physically. At the high temperature of 520° F., thickening and the formation of a jelly-like mass occurs. The retention of this mass at this temperature for some

time gradually results in the formation of a porous, polymerized product which may be cut easily with a knife, while hot, like ginger-bread. Several of the observers commented upon the semi-solid state of the mass around the sides of the vessels in which the heat tests were conducted. This same condition is observed even with constant stirring of the oil during the initial stages of polymerization, but is obviated if a temperature of 540° F. rather than 520° F. is maintained. At the higher temperature much better results are obtained. The Committee on Wood Oil Tests of the New York Produce Exchange has recently adopted a heat test for determining the purity of wood oil, and their specifications state that the oil shall be rapidly heated to 540° F. and held at that temperature for 7½ minutes. It is stated that complete polymerization is shown by all pure wood oils in such a test.

The McIlhiney test,[1] in which the iodine non-precipitable matter was estimated, did not in every case give concordant results. The analytical procedure is subject to improvement.

The Hanus and Wijs methods for determining the iodine number of oil have not given satisfactory results with wood oil in the past. The Hübl method is apparently better adapted for this purpose. Whether the 18-hour test is necessary, is a question that should be determined by additional tests.

A further report of the sub-committee on "Specifications for Turpentine" is given in Appendix II to this report (pages 365–368).

Respectfully submitted on behalf of the sub-committee,

H. A. GARDNER,
Chairman.

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[1] *Journal of Industrial and Engineering Chemistry*, 1912.

APPENDIX I.

DETAIL RESULTS OF TESTS OF SOYA BEAN OILS AND TUNG OILS.

TABLE III.—SOYA BEAN OIL NO. 1.

Observer.	Sp. Gr. at 15°.5 C.	Saponification Number.	Iodine Number, Hanus.	Acid Number.	Heat Test Remarks.	Sp. Gr. Heated Oil.	Change in Weight of Heated Oil in 3 days, per cent.	Remarks.	Color Value.[1]
Gardner	0.9210	190.0	132.6	1.20	Same color; viscous.	0.926	1.20+		
Boughton	0.9248	197.4	134.1	2.50	Bleached	0.943	3.10+		10mm.
Lindsay	0.9248	190.2	133.7	1.21	Bleached well	0.959	6.86+		
Lawrie	0.9220	191.4	132.0	2.40	Bleached	0.937	1.10+		
Toch	0.9250	196.5	129.7	2.20	Good	.....	10.00+		
Jackman & Stoppel	0.9248	192.4	132.2	2.24	Darkened	0.959	0.28+	Oil crawled on plate in drying test.	
Kohr & Mougey	0.9248	194.9	135.2	1.30	Same color	0.951	0.39+	Blown 12 hr.	
Pickard	0.9242	189.4	130.3	2.50	.....	.....	4.40+		
White & Boyle	0.9248	191.1	131.4	1.09	.....	.....	0.47+		
Average	0.9240	192.6	132.4	1.85	.....	0.944	3.09+		

[1] *Color.*—The color was compared with standard Lovibond glasses in a Schreiner colorimeter. A depth of 10 mm. of soya bean oil No. 1 was matched against a combination of glasses and used as a standard against which different depths of the other oils were matched.

TABLE IV.—SOYA BEAN OIL NO. 2.

Observer.	Sp. Gr. at 15°.5 C.	Saponification Number.	Iodine Number, Hanus.	Acid Number.	Heat Test Remarks.	Sp. Gr. Heated Oil.	Change in Weight of Heated Oil in 3 days, per cent.	Remarks.	Color Value.
Gardner	0.9210	190.0	135.2	2.50	Same color; viscous.	0.924	Lost		
Boughton	0.9251	196.3	135.3	2.10	Bleached slightly.	0.941	0.10+		9 mm.
Lindsay	0.9246	188.3	134.2	2.29	Bleached	0.959	6.40+		
Lawrie	0.9210	194.4	132.4	1.90	Bleached	0.946	0.90+		
Toch	0.9250	191.0	130.5	2.10	Good	.....	12.00+		
Jackman & Stoppel	0.9249	191.7	133.9	1.96	Darkened	0.952	0.12+	Oil crawled on plate in drying test.	
Kohr & Mougey	0.9257	189.0	137.3	2.30	Same color	0.950	0.19+	Blown 12 hr.	
Pickard	0.9246	185.6	133.8	2.20	.....	.....	3.20+		
White & Boyle	0.9248	191.0	131.1	2.11	.....	.....	1.31+		
Average	0.9241	190.8	133.7	2.16	.....	0.945	3.03+		

TABLE V.—SOYA BEAN OIL NO. 3.[1]

Observer.	Sp. Gr. at 15° .5 C.	Saponification Number.	Iodine Number, Hanus.	Acid Number.	Heat Test Remarks.	Sp. Gr. Heated Oil.	Change in Weight of Heated Oil in 3 days, per cent.	Remarks.	Color Value.
Gardner	0.9320	191.0	126.8	3.50	Darker; viscous	0.931	0.50+		
Boughton	0.9357	198.2	128.3	3.60	Same color	0.952	4.35+		6 mm.
Lindsay	0.9350	194.1	126.2	3.60	Darkened	0.959	9.87+		
Lawrie	0.9310	190.6	123.2	2.80	Darkened	0.941	1.30+		
Toch	0.9350	192.0	119.4	3.60	Same color	.....	10.30+		
Jackman & Stoppel	0.9355	194.9	122.7	3.36	Darkened	0.950	0.43+		
Kohr & Mougey	0.9361	193.8	129.2	3.60	Darkened	0.949	0.60+	Blown 12 hr.	
Pickard	0.9352	187.6	126.0	3.70	.....	.....	6.10+		
White & Boyle	0.9354	195.0	120.6	3.62	.....	.....	4.76+		
Average	0.9345	193.0	124.7	3.49	.....	0.947	4.25+		

[1] On account of the low constants shown by this oil, it was not considered pure and the constants were not included in the averages.

TABLE VI.—SOYA BEAN OIL NO. 5.

Observer.	Sp. Gr. at 15° .5 C.	Saponification Number.	Iodine Number, Hanus.	Acid Number.	Heat Test Remarks.	Sp. Gr. Heated Oil.	Change in Weight of Heated Oil in 3 days, per cent.	Remarks.	Color Value.
Gardner	0.9220	194.0	134.5	3.10	Lighter	0.925	0.10+		
Boughton	0.9256	197.7	134.9	3.30	Bleached	0.945	6.70+		10 mm.
Lindsay	0.9255	191.0	134.9	3.31	Bleached slightly.	0.962	6.07+		
Lawrie	0.9200	198.5	131.3	2.80	Bleached	0.971	0.80+		
Toch	0.9340	194.8	130.7	3.30	Bleached slightly.	.....	10.70+		
Jackman & Stoppel	0.9257	194.3	132.6	2.80	Darkened	0.954	0.13+	Oil crawled on plate in drying test.	
Kohr & Mougey	0.9252	192.3	136.3	3.50	Darkened	0.950	0.62+	Blown 21 hr.	
Pickard	0.9246	189.5	133.0	3.30	.....	.....	3.80+		
White & Boyle	0.9254	193.5	131.2	3.31	.....	.....	4.98+		
Average	0.9253	193.9	133.3	3.19	.....	0.951	3.77+		

TABLE VII.—SOYA BEAN OIL NO. 6 (BLOWN).

Observer.	Sp. Gr. at 15°.5 C.	Saponification Number.	Iodine Number, Hanus.	Acid Number.	Heat Test Remarks.	Sp. Gr. Heated Oil.	Change in Weight of Heated Oil in 3 days, per cent.	Remarks.	Color Value.
Gardner	0.9760	211.0	90.9	5.60	.....	0.976	Lost	Oil blown when submitted to committee.	
Boughton	0.9788	213.1	98.0	7.70	.....	.....	0.36+	"	27mm.
Lindsay	0.9750	.....	.....	.....	.....	.....	.....	"	
Lawrie	0.9730	193.3	88.3	6.00	.....	.....	1.30+	"	
Toch	0.9780	211.2	76.8	7.12	.....	.....	10.00+	"	
Jackman & Stoppel	0.9785	220.3	86.5	4.76	.....	.....	0.79+	"	
Kohr & Mougey	0.9785	203.9	94.8	7.30	.....	.....	.....	"	
Pickard	0.9760	207.6	95.9	6.90	.....	.....	3.60+	"	
White & Boyle	0.9756	197.0	90.2	6.64	.....	.....	2.62+	"	
Average	0.9766	207.2	90.2	6.50	.....	.....	3.11+	"	

TABLE VIII.—SOYA BEAN OIL NO. 7.

Observer.	Sp. Gr. at 15°.5 C.	Saponification Number.	Iodine Number, Hanus.	Acid Number.	Heat Test Remarks.	Sp. Gr. Heated Oil.	Change in Weight of Heated Oil in 3 days, per cent.	Remarks.	Color Value.
Gardner	0.9220	191.0	134.1	1.80	Lighter; viscous.	0.925	0.90+		
Boughton	0.9253	196.4	133.8	1.70	Bleachedslightly.	0.948	0.65+		10mm.
Lindsay	0.9252	189.6	134.9	1.58	Same color	0.951	6.35+		
Lawrie	0.9220	192.0	133.1	1.40	Bleached	0.923	1.60+		
Toch	0.9245	194.5	129.6	1.80	Good	.....	11.10+		
Jackman & Stoppel	0.9254	192.1	132.2	1.54	Bleached	0.950	1.28+	Oil crawled on plate in drying test.	
Kohr & Mougey	0.9250	193.9	135.2	1.90	Much darker	0.950	.....	Blown 17 hr.	
Pickard	0.9248	189.1	133.5	1.60	.....	.....	6.80+		
White & Boyle	0.9248	193.0	130.4	1.70	.....	.....	2.96+		
Average	0.9243	192.1	132.9	1.67	.....	0.941	3.96+		

TABLE IX.—SOYA BEAN OIL NO. 8.

Observer.	Sp. Gr. at 15°.5 C.	Saponification Number.	Iodine Number, Hanus.	Acid Number.	Heat Test Remarks.	Sp. Gr. Heated Oil.	Change in Weight of Heated Oil in 3 days, per cent.	Remarks.	Color Value.
Gardner	0.9240	195.0	136.3	1.00	Lighter; viscous	0.924	0.90+		
Boughton	0.9244	192.3	136.3	0.50	Bleached	0.951	0.35+		10mm.
Lindsay	0.9244	191.3	134.6	0.92	Bleached	0.955	8.02+		
Lawrie	0.9200	191.6	133.3	0.60	Bleached	0.923	Lost		
Toch	0.9250	191.3	130.6	0.81	Good	.....	15.60+		
Jackman & Stoppel	0.9248	192.4	132.8	0.70	Bleached	0.950	0.53+	Oil crawled on plate in drying test.	
Kohr & Mougey	0.9242	188.9	136.2	1.00	Same color	0.950	0.25+	Blown 11 hr.	
Pickard	0.9245	187.1	135.1	0.76	.....	.....	0.87+		
White & Boyle	0.9239	196.0	131.6	0.89	.....	.....	0.32+		
Average	0.9239	191.8	134.1	0.80	.....	0.942	3.36+		

TABLE X.—SOYA BEAN OIL NO. 9.

Observer.	Sp. Gr. at 15°.5 C.	Saponification Number.	Iodine Number, Hanus.	Acid Number.	Heat Test Remarks.	Sp. Gr. Heated Oil.	Change in Weight of Heated Oil in 3 days, per cent.	Remarks.	Color Value.
Gardner	0.9220	198.0	138.1	1.50	Darker; viscous	0.924	0.30+		
Boughton	0.9260	193.6	139.0	1.70	Same color	0.946	0.20+		4 mm.
Lindsay	0.9263	191.2	137.7	1.70	Bleached well	0.956	4.23+		
Lawrie	0.9210	192.8	134.9	1.40	Bleached	0.970	0.20+		
Toch	0.9262	195.8	132.9	1.50	Good	.....	11.90+		
Jackman & Stoppel	0.9258	192.8	136.3	1.54	Bleached	0.955	3.45+		
Kohr & Mougey	0.9260	190.3	139.3	1.70	Darkened slightly.	0.960	0.08−	Blown 12 hr.	
Pickard	0.9254	185.9	139.2	1.60	.....	.....	3.40+		
White & Boyle	0.9255	195.0	134.3	1.62	.....	.....	3.54+		
Average	0.9249	192.8	136.9	1.58	.....	0.950	3.02+		

TABLE XI.—SOYA BEAN OIL NO. 10.

Observer.	Sp. Gr. at 15° .5 C.	Saponification Number.	Iodine Number, Hanus.	Acid Number.	Heat Test Remarks.	Sp. Gr. Heated Oil.	Change in Weight of Heated Oil in 3 days, per cent.	Remarks.	Color Value.
Gardner	0.9230	191.0	138.5	1.40	Lighter; viscous.	0.925	2.00+		
Boughton	0.9260	914.8	137.8	1.50	Same color	0.953	0.95+		4 mm.
Lindsay	0.9260	191.4	136.4	1.57	Bleached well	0.962	2.26+		
Lawrie	0.9220	192.8	134.8	1.10	Bleached	0.971	1.10+		
Toch	0.9260	193.8	134.5	1.23	Fair	.....	15.00+		
Jackman & Stoppel	0.9259	192.8	135.7	1.26	Bleached	0.949	1.09+		
Kohr & Mougey	0.9269	187.6	139.5	1.50	.....	0.950	0.26−	Blown 10 hr.	
Pickard	0.9255	188.8	137.3	1.30	.....	.....	3.10+		
White & Boyle	0.9255	190.0	133.7	1.47	.....	.....	7.24+		
Average	0.9252	191.4	136.6	1.37	.....	0.952	3.61+		

TABLE XII.—SOYA BEAN OIL NO. 11.

Observer.	Sp. Gr. at 15° .5 C.	Saponification Number.	Iodine Number, Hanus.	Acid Number.	Heat Test Remarks.	Sp. Gr. Heated Oil.	Change in Weight of Heated Oil in 3 days, per cent.	Remarks.	Color Value.
Gardner	0.9230	192.0	137.8	3.70	Darker; viscous.	0.923	0.80+		
Boughton	0.9263	194.3	139.0	5.60	Same color	0.943	0.35+		6 mm.
Lindsay	0.9263	191.6	137.4	4.45	Same color	0.964	5.17+		
Lawrie	0.9220	190.5	134.7	3.40	Bleached	0.943	2.70+	Dark brown precipitate formed.	
Toch	0.9270	193.4	134.4	3.50	Bleached slightly.	.....	10.00+		
Jackman & Stoppel	0.9265	192.4	135.7	4.48	Darkened	0.955	1.66+		
Kohr & Mougey	0.9267	187.9	138.8	5.80	Darkened slightly.	0.950	1.02+	Blown 10 hr.	
Pickard	0.9260	187.8	138.6	5.90	.....	.....	6.30+		
White & Boyle	0.9251	191.0	133.7	4.83	.....	.....	5.85+		
Average	0.9254	191.2	136.7	4.63	.....	0.946	3.76+		

TABLE XIII.—SOYA BEAN OIL NO. 12.

Observer.	Sp. Gr. at 15°.5 C.	Saponification Number.	Iodine Number, Hanus.	Acid Number.	Heat Test Remarks.	Sp. Gr. Heated Oil.	Change in Weight of Heated Oil in 3 days, per cent.	Remarks.	Color Value.
Gardner	0.9220	190.0	133.1	1.80	Darker; viscous.	0.924	3.50+		
Boughton	0.9265	194.3	138.7	2.10	Same color	0.954	0.15+		8 mm.
Lindsay	0.9263	190.4	135.3	2.17	Darkened slightly.	0.959	6.23+		
Lawrie	0.9220	193.7	132.2	1.70	Darkened	Lost	3.10+	Dark brown precipitate formed.	
Toch	0.9260	192.2	132.6	1.94	.....	.....	10.40+		
Jackman & Stoppel	0.9265	192.8	134.5	1.82	Darkened	0.953	6.48+		
Kohr & Mougey	0.9269	189.4	137.4	2.40	Darkened	0.950	0.41+	Blown 15 hr.	
Pickard	0.9259	187.5	133.5	2.20	.....	.....	7.50+		
White & Boyle	0.9257	191.0	131.0	1.94	.....	.....	7.05+		
Average	0.9253	191.3	134.3	2.01	.....	0.948	4.98+		

TABLE XIV.—TUNG OIL NO. 20.

Observer.	Sp. Gr. at 15°.5 C.	Saponification Number.	Iodine Number, Hübl, 18 hr.	Acid Number.	Heat Test at 420° F., 20 min.	Heat Test at 520° F., Remarks.	McIlhiney Test,[1] per cent.	Remarks.	Color Value.[2]
Gardner	0.9370	192.0	169.4	4.60	Polymerized around edge.	Polymerized completely in 6 min.; medium color.	37.90	Good quality.	
Boughton	0.9415	197.0	162.6	6.20	Not polymerized.	Jelly-like; cut clean.	.....		10 mm.
Lindsay	0.9408	192.1	170.9	6.16	Sticky at edge	Polymerized; cut clean in center.	12.18		
Lawrie	0.9370	193.7	171.3	4.40	Polymerized slightly.	Polymerized completely.	13.90		
Toch	0.9400	192.3	167.8	6.30	.....	.....	.....		
Jackman & Stoppel	0.9409	193.4	168.5	4.76	Unchanged	Polymerized	18.54		
Kohr & Mougey	0.9420	191.0	172.5	6.40	No action	Solidified in 7 min.	.....		
Pickard	0.9399	190.9	159.6	6.10	Polymerized around edge.	Jelly-like; cut clean.	21.80		
White & Boyle	0.9392	193.8	171.5	6.18	No change	Polymerized	.....		
Average	0.9398	192.9	168.2	5.68	.....	.....	20.86		

[1] *Journal of Industrial and Engineering Chemistry*, 1912.

[2] *Color.*—The color was compared with standard Lovibond glasses in a Schreiner colorimeter. A depth of 10 mm. of tung oil No. 20 was matched against a combination of glasses and used as a standard against which different depths of the other oils were matched.

TABLE XV.—TUNG OIL NO. 21.

Observer.	Sp. Gr. at 15°.5 C.	Saponification Number.	Iodine Number, Hübl, 18 hr.	Acid Number.	Heat Test at 420° F., 20 min.	Heat Test at 520° F., Remarks.	McIlhiney Test, per cent.	Remarks.	Color Value.
Gardner	0.9390	193.0	169.6	12.50	Polymerized around edge.	Polymerized completely in 6 min.; medium color.	37.90	Good quality.	
Boughton	0.9430	199.3	164.8	10.20	Not polymerized.	Jelly-like; cut clean.	.....		11 mm.
Lindsay	0.9425	193.6	172.1	10.96	Sticky at edge.	Polymerized; cut clean in center.	14.25		
Lawrie	0.9390	190.8	172.6	8.10	Polymerized slightly.	Polymerized completely.	13.00		
Toch	0.9430	196.8	165.4	10.50	.....	.....	.....		
Jackman & Stoppel	0.9424	193.3	169.0	8.26	Unchanged	Polymerized	16.54		
Kohr & Mougey	0.9433	191.2	170.2	10.90	No action	Solidified in 5 min.	.....		
Pickard	0.9414	191.2	161.6	10.70	Polymerized around edge.	Jelly-like; cut clean.	22.30		
White & Boyle	0.9398	199.6	171.9	10.38	No change	Polymerized	.....		
Average	0.9415	194.3	168.6	10.28	.....	.....	20.80		

TABLE XVI.—TUNG OIL NO. 22.

Observer.	Sp. Gr. at 15°.5 C.	Saponification Number.	Iodine Number, Hübl, 18 hr.	Acid Number.	Heat Test at 420° F., 20 min.	Heat Test at 520° F., Remarks.	McIlhiney Test, per cent.	Remarks.	Color Value.
Gardner	0.9370	186.0	163.5	1.80	Polymerized slightly around edge.	Polymerized completely in 10 min.; very light color.	37.00	Good quality.	
Boughton	0.9415	196.6	163.1	2.00	Not polymerized.	Jelly-like; cut clean.	.....		22 mm.
Lindsay	0.9408	191.6	173.9	2.07	Sticky at edge	Polymerized; cut clean in center.	11.68		
Lawrie	0.9380	191.3	171.4	1.30	Polymerized slightly.	Polymerized completely.	10.40		
Toch	0.9430	192.6	161.8	1.29	.....	.....	.....		
Jackman & Stoppel	0.9409	192.8	168.6	1.40	Unchanged	Polymerized	11.87		
Kohr & Mougey	0.9415	187.7	172.0	2.20	No action	Solidified in 8 min.	.....		
Pickard	0.9400	187.9	160.6	1.70	Polymerized around edge.	Jelly-like; cut clean.	13.70		
White & Boyle	0.9388	196.9	172.6	1.84	No change	Polymerized	.....		
Average	0.9402	191.5	167.5	1.73	.....	.....	16.93		

TABLE XVII.—TUNG OIL NO. 23.

Observer.	Sp. Gr. at 15°.5 C.	Saponification Number.	Iodine Number, Hübl, 18 hr.	Acid Number.	Heat Test at 420° F., 20 min.	Heat Test at 520° F., Remarks.	McIlhiney Test, per cent.	Remarks.	Color Value.
Gardner	0.9380	194.0	166.3	7.20	Polymerized slightly around edge.	Polymerized completely in 9 min.; dark color.	38.40	Not as good as Nos. 20 and 21.	
Boughton	0.9405	195.7	163.0	9.10	Not polymerized.	Jelly-like; cut clean.	18.60	Very turbid oil.	12mm.
Lindsay	0.9408	193.0	172.3	8.91	.....	Jelly-like and sticky.	20.25		
Lawrie	0.9380	193.3	170.0	6.00	Polymerized slightly.	Polymerized completely.	18.90		
Toch	0.9410	196.2	164.4	9.30	.....	.....	.....		
Jackman & Stoppel	0.9408	194.1	168.0	6.72	Unchanged	Polymerized	20.94		
Kohr & Mougey	0.9420	188.1	172.5	7.40	No action	Solidified in 5 min.	.....		
Pickard	0.9403	190.9	163.2	8.30	Polymerized around edge.	Jelly-like; cut clean.	33.40		
White & Boyle	0.9400	.....	170.6	8.36	No change	Polymerized	.....		
Average	0.9402	193.2	167.8	7.92	.....	.....	25.08		

TABLE XVIII.—TUNG OIL NO. 25.

Observer.	Sp. Gr. at 15°.5 C.	Saponification Number.	Iodine Number, Hübl, 18 hr.	Acid Number.	Heat Test at 420° F., 20 min.	Heat Test at 520° F., Remarks.	McIlhiney Test, per cent.	Remarks.	Color Value.
Gardner	0.9370	189.0	169.2	8.40	Polymerized slightly around edge.	Polymerized completely in 10 min.; very dark color.	29.00	Good.	
Boughton	0.9407	197.2	164.4	10.00	Not polymerized.	Jelly-like; cut clean.	14.70		12mm.
Lindsay	0.9402	191.5	173.5	10.05	Sticky jelly	Did not cut clean.	12.53		
Lawrie	0.9380	188.3	172.5	6.50	Polymerized slightly.	Polymerized completely; slower than others.	10.90		
Toch	0.9405	195.2	164.5	9.30	.....	.....	.....		
Jackman & Stoppel	0.9402	192.4	168.4	7.70	Unchanged	Polymerized	16.51		
Kohr & Mougey	0.9417	193.3	172.6	10.40	No action	Solidified in 8 min.	.....		
Pickard	0.9401	189.9	161.8	9.50	Polymerized around edge.	Jelly-like; cut clean.	19.50		
White & Boyle	0.9391	.....	173.8	9.72	No change	Polymerized (sticky).	.....		
Average	0.9397	192.1	168.0	9.06	.....	.....	17.19		

TABLE XIX.—TUNG OIL NO. 26.

Observer.	Sp. Gr. at 15°.5 C.	Saponification Number.	Iodine Number, Hübl, 18 hr.	Acid Number.	Heat Test at 420° F., 20 min.	Heat Test at 520° F., Remarks.	McIlhiney Test, per cent.	Remarks.	Color Value.
Gardner	0.9390	193.0	167.7	1.90	Polymerized slightly around edge.	Polymerized completely in 4 min.; very dark color.	21.10	Very good quality.	
Boughton	0.9423	196.0	167.7	2.90	Not polymerized.	Jelly-like; cut clean.	.....	Strong odor.	9 mm.
Lindsay	0.9421	190.9	174.3	1.86	Sticky at edge	Polymerized; cut clean in center.	11.84		
Lawrie	0.9390	192.0	173.0	1.50	Polymerized slightly.	Polymerized completely.	11.10		
Toch	0.9430	194.9	167.2	1.73	.....	.....	.....		
Jackman & Stoppel	0.9423	192.5	169.4	1.70	Unchanged	Polymerized	12.50		
Kohr & Mougey	0.9433	192.6	170.3	1.70	No action	Solidified in 5 min.	.....		
Pickard	0.9419	188.3	159.9	1.90	Polymerized around edge.	Jelly-like; cut clean.	15.60		
White & Boyle	0.9401	.....	175.5	1.60	No change	Polymerized	.....		
Average	0.9414	192.5	169.4	1.87	.....	.....	14.43		

TABLE XX.—TUNG OIL NO. 27.

Observer.	Sp. Gr. at 15°.5 C.	Saponification Number.	Iodine Number, Hübl, 18 hr.	Acid Number.	Heat Test at 420° F., 20 min.	Heat Test at 520° F., Remarks.	McIlhiney Test, per cent.	Remarks.	Color Value.
Gardner	0.9380	193.0	171.2	6.20	Polymerized slightly around edge.	Polymerized completely in 10 min.; medium color.	31.40	Good quality.	
Boughton	0.9413	198.1	165.4	8.10	Not polymerized.	Jelly-like; cut clean.	.....		18 mm
Lindsay	0.9402	192.2	173.8	8.06	Sticky at edge	Polymerized; cut clean in center.	10.51		
Lawrie	0.9380	191.8	172.1	5.30	Polymerized slightly.	Polymerized completely.	10.70		
Toch	0.9415	196.2	166.3	7.70	.....	.....	.....		
Jackman & Stoppel	0.9413	194.1	171.6	6.02	Unchanged	Polymerized	15.26		
Kohr & Mougey	0.9425	193.0	173.6	8.10	No action	Solidified in 5 min.	.....		
Pickard	0.9411	188.9	171.7	7.90	Polymerized around edge.	Jelly-like; cut clean.	7.20		
White & Boyle	0.9394	.....	174.1	7.67	No change	Polymerized	.....		
Average	0.9404	193.4	171.1	7.23	.....	.....	15.01		

TABLE XXI.—TUNG OIL NO. 28.

Observer.	Sp. Gr. at 15°.5 C.	Saponification Number.	Iodine Number, Hübl, 18 hr.	Acid Number.	Heat Test at 420° F., 20 min.	Heat Test at 520° F., Remarks.	McIlhiney Test, per cent.	Remarks.	Color Value.
Gardner	0.9400	195.0	171.2	1.00	Polymerized slightly around edge.	Polymerized completely in 10 min.; very light color.	14.10	Fair quality.	
Boughton	0.9436	196.1	165.1	1.30	Not polymerized.	Jelly-like; cut clean.	.....		10 mm
Lindsay	0.9428	191.9	174.6	1.40	Sticky at edge.	Polymerized; cut clean in center.	11.42		
Lawrie	0.9400	191.6	173.0	6.70	Polymerized slightly.	Polymerized completely; slower than others.	9.60		
Toch	0.9400	193.5	170.4	0.98	.....	.....	.....		
Jackman & Stoppel	0.9434	192.8	170.5	0.84	Unchanged	Polymerized	11.93		
Kohr & Mougey	0.9441	194.3	172.7	1.00	No action	Solidified in 6 min.	.....		
Pickard	0.9432	189.5	163.3	1.20	Polymerized around edge.	Jelly-like; cut clean.	13.50		
White & Boyle	0.9425	.....	174.6	1.11	No change	Polymerized	.....		
Average	0.9422	193.1	170.6	1.73	.....	.....	12.11		

ADDENDA

TABLE XXII.—DATA ON DENSITY OF OILS[1] USED IN TESTS, BY H. C. BEARCE, BUREAU OF STANDARDS.

Density of Soya Bean Oils.

Oil No.	$D\frac{15°}{4°}$ C.	$D\frac{15°.5}{4°}$ C.	$D\frac{15°.5}{15°.5}$ C.	$D\frac{25°}{4°}$ C.	$D\frac{25°}{25°}$ C.	Between[2] 15°–30° C.	B. S. Nos.
1	0.92462	0.92427	0.92515	0.91761	0.92030	0.00070	3975
2	0.92460	0.92426	0.92514	0.91771	0.92040	0.00069	3976
3	0.93518	0.93484	0.93573	0.92829	0.93101	0.00069	3977
5	0.92532	0.92498	0.92586	0.91852	0.92121	0.00068	3978
6	0.97740	0.97706	0.97799	0.97058	0.97343	0.00068	3979
7	0.92499	0.92465	0.92553	0.91814	0.92083	0.00068	3980
8	0.92428	0.92394	0.92482	0.91750	0.92019	0.00068	3981
9	0.92544	0.92510	0.92598	0.91863	0.92132	0.00068	3982
10	0.92550	0.92516	0.92604	0.91866	0.92135	0.00068	3983
11	0.92648	0.92614	0.92702	0.91970	0.92240	0.00068	3984
12	0.92613	0.92579	0.92667	0.91930	0.92199	0.00068	3985

Density of Tung Oils.

20	0.93996	0.93963	0.94052	0.93331	0.93605	0.00067	3986
21	0.94204	0.94169	0.94259	0.93512	0.93786	0.00069	3987
22	0.94049	0.94015	0.94104	0.93360	0.93634	0.00069	3988
23	0.94044	0.94010	0.94099	0.93356	0.93630	0.00069	3989
25	0.93982	0.93948	0.94037	0.93262	0.93535	0.00069	3990
26	0.94201	0.94167	0.94257	0.93481	0.93755	0.00069	3991
27	0.94084	0.94050	0.94139	0.93362	0.93636	0.00069	3992
28	0.94296	0.94262	0.94352	0.93579	0.93853	0.00068	3993

[1] $D\frac{t}{t'}$ = specific gravity at t° referred to water at t'° as unity. When t'=4° C., the specific gravity is numerically the same as density in grams per cubic centimeter.

[2] Change of density per degree change of temperature.

APPENDIX II.

SPECIFICATIONS FOR TURPENTINE.

A meeting of Sub-Committee C was held on June 15, 1912, at The Institute of Industrial Research, Washington, D. C., and was attended by Messrs. Veitch, Boughton and Gardner. Communications from Messrs. Teeple, Gibboney and Herty were read at the meeting. Tentative specifications for turpentine were drawn up and submitted simply for consideration as follows:

TENTATIVE SPECIFICATIONS FOR TURPENTINE.

TURPENTINE. NO. 1.

These specifications apply both to the turpentine that is distilled from pine oleoresin and generally known as gum turpentine, and the turpentine that is distilled from wood and generally known as wood turpentine. The committee does not attempt to differentiate between the two, provided they fully meet all requirements. The purchaser when submitting these specifications may at his option specify either product.

Color.—The turpentine shall be perfectly clear, free from suspended material, and water white. The color shall be determined by matching a sample 200 mm. in depth with a No. 1 Lovibond glass in a Schreiner colorimeter. The turpentine shall not show a greater color than the standard glass.

Specific Gravity.—The specific gravity shall not be less than 0.862 nor more than 0.870 at 20° C.

Refractive Index.—The refractive index shall be from 1.468 to 1.476 at 20° C.

Boiling Point.—The boiling point shall be between 152° and 158° C.

Distillation Test.—When 200 cc. of the turpentine are distilled, 95 per cent shall pass over below 170° C.

For this test use a 300-cc. flask, 8 cm. in diameter, with a side tube 8 cm. from the main bulb, and the neck extending

8 cm. above the side tube. The neck is 2 cm. in diameter and the side tube is 5 mm. This flask should be fitted with a thermometer (reading from 145° to 200° C.) immersed in the vapor. The mercury bulb should be opposite the side tube of the flask and the reading 175° C. should be below the cork. The distillation should be so conducted that there shall pass over about two drops of the distillate per second.

Polymerization.—When 5 cc. of the sample are treated with sulphuric acid of specific gravity 1.84, according to the method herewith outlined there shall remain undissolved at the end of thirty minutes not over 0.09 cc. The residue unpolymerized should show a refraction value of not less than 1.50 to 1.52. It should be viscous in nature. If the residue is water-white, limpid, and does not show the proper refraction value, it should be carefully polymerized with 38-N sulphuric acid according to Veitch.[1]

For this test, add slowly 5 cc. of the turpentine to 25 cc. of 1.84 sulphuric acid contained in an ordinary graduated narrow-neck Babcock flask. Shake the flask with a rotary motion to insure gradual mixing. Cool, if necessary, in ice water, not permitting the temperature to rise above 60° to 65° C. Agitate thoroughly, and maintain at about 65° C. with frequent agitations for one hour. Cool, fill the flask with sulphuric acid, bringing the unpolymerized oil into the graduated neck. Allow to stand one hour. Read off the umpolymerized content, note its consistency and color, and determine its refractive index.

Color Test.—Shake 10 cc. of the turpentine with 10 cc. of concentrated hydrochloric acid in a test tube. The development, after three minutes standing, of a decided red color is indicative of the presence of other (usually heavy) resinous oils.

Evaporation Test.—Place 10 cc. of the sample in a glass crystallizing dish, $2\frac{1}{2}$ in. in diameter and $1\frac{1}{8}$ in. high, and evaporate on an open steam bath with a full head of steam until there is no more loss in weight. The residue shall not weigh more than 0.150 g.

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[1] *Bulletin No. 135*, p. 30, or *Circular No. 85*, Bureau of Chemistry, Department of Agriculture.

On November 16, 1912, the above specifications were considered at the meeting of the committee held at the Bureau of Chemistry, Washington, D. C. It was decided not to recommend any specifications for adoption until tests had been made upon samples of turpentine obtained by members of the committee from authoritative and reliable sources. Members of the committee will secure such samples in the field at the time of manufacture, and quantities of each sample will be submitted to the various members of the committee to use in studying the methods embraced in the foregoing tentative specifications. The procedure for this work which was then submitted to the committee is as follows:

SUGGESTED PROCEDURE FOR THE ANALYSIS OF TURPENTINE.

Color.—Note and report whether the material is free from dirt and suspended matter and is water white. Determine the color by comparing a sample 200 mm. in depth over a No. 1 Lovibond glass, with a No. 2 Lovibond glass in a colorimeter. Note and report whether the turpentine plus the No. 1 glass is lighter or darker in color than the No. 2 glass.

Specific Gravity.—Determine the specific gravity by any suitable accurate method and report figure as specific gravity at 15°.5/15°.5 C. State method used.

Refractive Index.—Determine with a direct reading refractometer at 15°.5 C.

Distillation Test.

Test 1.—For this test use a 300-cc. flask, 8 cm. in diameter, with a side tube 8 cm. from the main bulb, and the neck extending 8 cm. above the side tube. The neck is 2 cm. in diameter and the side tube is 5 mm. This flask should be fitted with a thermometer (reading from 145° to 200° C.) immersed in the vapor. The mercury bulb should be opposite the side tube of the flask and the reading 175° C. should be below the cork. The distillation should be so conducted that there shall pass over about two drops of the distillate per second.

Test 2.—For this test use the ordinary Engler flask as shown on page 503 of *Engineering Chemistry* by Stillman. Have the thermometer totally immersed in the vapor as directed in the specifications in Test 1. In Test 2 use 100 cc. of turpentine to determine whether the same results are obtained as with 200 cc. of turpentine.

Test 3.—Use the ordinary Engler flask as described in Test 2, and an ordinary long stem thermometer. Determine approximate length of the mercury column outside the flask at the distillation temperatures.

In all three methods of distillation note and report the initial boiling point and the percentage of distillate obtained below 170° C., and the barometric pressure at the time of making the distillation.

Polymerization.

Test 1.—Add slowly 5 cc. of the turpentine to 25 cc. of 1.84 sulphuric acid contained in an ordinary graduated narrow-neck Babcock flask. Shake the flask with a rotary motion to insure gradual mixing. Cool, if necessary, in ice water, not permitting the temperature to rise above 60° to 65° C. Agitate thoroughly and maintain at about 65° C. with frequent agitations for one hour. Cool, fill the flask with sulphuric acid, bringing the unpolymerized oil into the graduated neck. Allow to stand one hour. Read off the unpolymerized content; note and report its consistency and color, and determine its refractive index at 15°.5 C.

Test 2 (Veitch's Method[1]).—Repeat Test 1, but use 38-N sulphuric acid and let flasks stand 24 hours before reading the amount of unpolymerized residue, or else centrifuge five minutes.

Hydrochloric Acid Test.—Shake 10 cc. of the turpentine with 10 cc. of concentrated hydrocloric acid, specific gravity 1.19. Note whether after three minutes standing a decided red color develops. Test for the presence of other usually heavy or resinous oils.

Evaporation Test.—Place 10 cc. of the sample in a glass crystallizing dish, 2½ in. in diameter and 1¼ in. high, and evaporate on an open steam bath with a full head of steam for 2 hours. Cool, weigh, and report weight of residue in grams.

Flash Point.

Test 1.—Support a 100-cc. nickel crucible, such as is used in determining the flash point of linseed oil, in a vessel of water at 15° to 20° C.; the water should cover about two-thirds of the crucible. Fill the crucible to within about 2 cm. of the top with turpentine, insert a thermometer, and heat the water bath slowly so that the temperature of the turpentine rises 1° C. per minute. Begin at 37° C. and test for the flash at each rise of 0°.5 C. Report temperature at which the turpentine flashes.

Test 2.—Determine the flash point using the Tagliabue open cup. Begin testing at 30° C. and test at each degree Centigrade above that till the sample flashes. The temperature of the turpentine should not rise more rapidly than 1° C. per minute.

Test 3.—Use a closed tester such as the Pensky-Martin tester, the Abel cup, etc., following the directions for the instrument.

It is thought that the authoritative samples for the tests will not be received before the end of June. The report on the tests will therefore be made next year.

Respectfully submitted on behalf of the sub-committee,

H. A. GARDNER,
Chairman.

[1] *Bulletin No. 135*, p. 30, or *Circular No. 85*, Bureau of Chemistry, Department of Agriculture.

REPORT OF SUB-COMMITTEE D ON THE ATLANTIC CITY STEEL PAINT TESTS.

The Atlantic City Steel Paint Tests were originally designed by members of the American Society for Testing Materials, with the object in view of determining by practical exposure tests whether certain single pigments would, when enveloped in an oil film, offer the same relation to the protection or to the corrosion of iron or steel that was exhibited by these pigments in laboratory tests when placed in contact with steel plates in the presence of water. A series of pigments which had been under experimentation in the water tests were therefore selected for the exposure tests and after being ground in linseed oil, the quantity of which was determined in every instance by the specific gravity of the individual pigments, were applied to steel and iron plates and subjected to exposure. That the results obtained from these tests would have been modified to some degree had the tests been made more diversified in respect to the quantity of liquids used in the grinding of the pigments, there can be no doubt. It is, however, fair to state that the tests have offered considerable information as to the relative value of various pigments as components of structural paints and that they have presented much valuable data upon which to base future tests of a more extended nature.

Although a complete history of the tests, including the data regarding the preparation and application of the paints, is to be found in the Proceedings of the Society,[1] the committee is presenting herewith, for the benefit of those who are not familiar with previous reports, an outline of the tests as summarized in the Proceedings of 1910:

"Three years ago the suggestion was made in a paper presented before the Tenth Annual Meeting of this Society,[2] that the various types of substances used as pigments in protective coatings might exert a stimulative or an inhibitive action on the rate and tendency to corrosion of the underlying metal. It was further suggested on theoretical grounds that slightly soluble chromates should exert a protective action when employed

[1] Vol. IX, pp. 203–204 (1909); Vol. X, pp. 73–86 (1910); Vol. XI, pp. 192–194 (1911).
[2] "The Corrosion of Iron," A. S. Cushman, *Proceedings*, Vol. VII, p. 211 (1907).

as pigments, by maintaining the surface of the iron in a passive condition in case water and oxygen penetrated the paint film. In view also of the well-known fact that alkalies inhibit while acids stimulate the corrosion of iron, it was suggested that the action of more or less pure pigments on iron in the presence of water be thoroughly investigated. Two years ago this committee invited the cooperation of Committee D-1 (then known as Committee E) in the investigation, and a special sub-committee representing the two main committees was appointed.

"Briefly, the method consisted in immersing samples of steel in water suspensions of the various pigments and blowing air through the containers for definite periods of time, the corrosion being measured by the loss in weight sustained by the test pieces. About fifty pigments which are in more or less common use for painting steel were purchased in the open market and distributed among a number of the members of the committee, who agreed to carry out the work. Each investigator worked independently of the others, except that the same general method was followed; the time of exposure to the corroding action, however, varied in the different experiments. When the results were compared and analyzed by the sub-committee, it was felt that the general agreement of the results obtained by the several investigators was striking and merited further and more systematic work. As a result of these tests the sub-committee tentatively divided the pigments into inhibitors, stimulators, and indeterminates. The word 'indeterminate' was selected after considerable discussion, because the words 'neutral' or 'inert' already possess a special meaning as applied to paint technology. The committee takes this occasion to emphatically state that in adopting this tentative classification, the words 'inhibitive' and 'stimulative' as used by them up to the present time apply only to the results obtained in the water tests, and the inference that the results obtained have decided which class the pigment will fall into when made into a paint with the usual vehicles and used as a protective coating on iron and steel, is not justified. In order to make this point quite clear, it has been agreed by the committee to qualify the classification so as to speak of the various materials tested as 'water stimulative' or 'water inhibitive.'

"As a result of the preliminary tests, it seems desirable

TABLE I.—THIRD AND FOURTH ANNUAL INSPECTIONS

Panel.	Pigment.	Original classification in water tests.	Average Rating, 1911 Inspection.	H. A. Gardner.	C. S
1	Dutch process white lead	Inhib.	3.7	2.0	
2	Quick process white lead	Indet.	4.2	2.0	
3	Zinc oxide	Inhib.	1.5	1.0	
4	Sublimed white lead	Indet.	9.0	9.0	
5	Sublimed blue lead	Indet.	8.8	9.0	
6	Lithopone	Indet.	2.2	1.0	
7	Zinc lead white	Inhib.	4.7	4.0	
9	American orange mineral	Indet.	8.3	6.0	
10	Red lead	Indet.	8.3	7.0	
12	Bright red oxide	Stim.	8.1	7.0	
14	Venetian red	Inhib.	8.0	7.0	
15	Prince's metallic brown	Inhib.	6.3	5.0	
16	Natural graphite	Stim.	6.8	5.0	
17	Artificial graphite	Stim.	5.9	4.0	
19	Lampblack (barytes)	Stim.	6.3	5.0	
20	Willow charcoal	Inhib.	8.8	9.0	
21	Gas carbon black (natural barytes)	Stim.	7.2	5.0	
24	French yellow ochre	Stim.	5.5	4.0	
27	Natural barytes	Stim.	0.7	0.0	
28	Precipitated barytes (blanc fixe)	Indet.	1.8	1.0	
29	Calcium carbonate (whiting)	Indet.	0.0	0.0	
30	Calcium carbonate (precipitated)	Indet.	0.0	0.0	
31	Calcium sulphate (gypsum)	Indet.	1.7	1.0	
32	China clay (kaolin)	Indet.	6.3	2.5	
33	Asbestine (magnesium silicate)	Indet.	5.1	1.0	
34	American vermilion (chrome scarlet)	Indet.	10.0	10.0	
36	Medium chrome yellow	Indet.	7.7	5.0	
39	Zinc chromate	Inhib.	9.5	9.0	
40	Zinc and barium chromate	Inhib.	9.5	8.0	
41	Chrome green (blue tone)	Inhib.	9.8	9.0	
44	Prussian blue	Stim.	9.0	8.0	
45	Prussian blue	Inhib.	8.5	7.5	
48	Ultramarine blue	Inhib.	0.0	0.0	
49	Zinc and lead chromate	Inhib.	9.7	9.0	
51	Magnetic black oxide[1]	.....	9.5	8.5	
	Composite Paints.				
111	Brown	Made from pigments that were inhibitive in the water test	.....	8.5	8.0
222	Black			8.8	6.0
333	White			4.5	2.0
444	Green			6.7	5.0
555	Black	Made from pigments that were stimulative in the water test	.....	8.2	7.0
666	Brown			7.7	6.0
777	White			7.2	3.0
888	Green			8.0	5.0
2000	1 coat zinc chromate, 1 coat iron oxide excluder	.....	8.1	7.0	
3000	1 coat lead chromate, 1 coat iron oxide excluder	.....	7.3	6.0	
4000	1 coat red lead, 1 coat iron oxide excluder	.....	7.7	6.0	
100	Straight carbon black paint, with turps and drier	.....	6.5	5.0	
90	Straight lampblack paint, with turps and drier	.....	5.7	4.0	
5555	Coal-tar paint over red lead	.....	5.2	3.0	

[1] Not included in water tests.

NUAL INSPECTIONS OF PAINT-TEST STEEL PANELS, ATLANTIC CITY N. J., BY SUB-COMMITTEE D OF

THIRD ANNUAL INSPECTION, 1912							
H. A. Gardner.	C. S. Neal.	Anderson Polk.	G. D. White.	G. H. Pickard.	J. W. Lawrie.	G. W. Thompson.	Average.
2.0	2.5	1.0	2.0	2.0	2.0	2.0	1.9
2.0	2.5	1.0	2.5	2.0	2.5	2.0	2.1
1.0	0.5	1.0	1.0	1.0	0.5	0.0	0.7
9.0	7.0	8.5	8.0	8.0	7.5	9.0	8.1
9.0	8.5	9.5	8.5	9.5	9.0	9.0	9.0
1.0	1.0	1.0	0.5	1.5	1.0	0.0	0.8
4.0	5.0	6.0	4.5	3.0	5.0	4.0	4.5
6.0	5.5	8.0	7.0	6.0	6.5	9.0	6.9
7.0	8.5	8.0	7.5	8.0	8.5	9.0	8.1
7.0	6.0	7.5	6.5	6.0	6.0	8.0	6.7
7.0	5.0	8.0	8.0	5.0	5.0	7.0	6.4
5.0	6.5	7.0	6.5	6.0	6.5	6.0	6.2
5.0	5.5	8.0	7.0	7.0	5.5	8.0	6.6
4.0	3.0	7.0	4.5	4.0	3.5	5.0	4.4
5.0	3.5	7.5	6.0	5.0	3.5	8.0	5.5
9.0	8.0	9.0	8.5	9.0	8.0	9.0	8.6
5.0	5.0	9.0	8.0	8.0	5.0	9.0	7.0
4.0	6.0	6.5	5.0	5.0	6.0	8.0	5.8
0.0	0.5	1.0	0.5	0.0	0.5	0.0	0.3
1.0	0.5	1.0	1.0	1.0	0.5	0.0	0.7
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.0	1.0	0.5	1.0	1.0	1.0	1.0	0.9
2.5	2.5	1.0	4.5	4.0	2.5	2.0	2.7
1.0	1.5	1.0	3.5	3.0	1.5	2.0	1.9
10.0	10.0	10.0	10.0	10.0	10.0	9.0	9.9
5.0	6.0	6.0	6.0	6.0	6.0	7.0	6.0
9.0	8.5	8.5	8.5	9.5	8.5	9.0	8.8
8.0	8.0	8.5	8.5	9.5	8.0	9.0	8.5
9.0	7.0	9.0	9.0	9.7	7.5	9.0	8.6
8.0	5.0	9.0	8.5	8.5	6.5	9.0	7.8
7.5	4.5	8.5	8.0	8.0	5.0	9.0	7.2
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.0	9.5	9.0	9.0	9.7	9.5	9.0	9.2
8.5	8.0	9.0	9.0	9.0	7.5	9.0	8.6
8.0	8.5	8.5	7.0	7.0	8.0	....	7.8
6.0	5.0	6.0	7.0	6.0	5.0	....	5.8
2.0	3.0	3.0	3.0	2.5	3.0	....	2.7
5.0	4.0	6.0	5.0	6.0	5.0	....	5.2
7.0	5.5	9.0	7.5	8.5	5.5	....	7.2
6.0	5.0	9.0	7.0	7.5	5.0	....	6.6
3.0	5.0	5.0	6.0	6.0	5.0	....	5.0
5.0	9.0	8.0	7.5	8.5	9.0	....	7.8
7.0	3.5	7.0	5.5	3.5	....	....	5.3
6.0	3.5	6.0	5.0	4.5	3.5	....	4.7
6.0	4.0	7.0	5.0	5.0	4.0	....	5.2
5.0	7.0	6.0	7.0	7.0	6.0	....	6.3
4.0	4.0	4.0	5.5	4.0	4.0	....	4.2
3.0	3.5	4.0	4.0	4.0	3.5	....	3.7

TEE D OF COMMITTEE D-1.

erage.	POURTH ANNUAL INSPECTION, 1913					Average.
	H. A. Gardner.	W. H. Walker.	C. S. Neal.	G. D. White.	C. M. Chapman.	
1.9	0.5	0.5	2.0	1.0	2.5	1.3
2.1	0.5	0.5	2.0	1.0	2.5	1.3
0.7	0.5	0.0	2.0	0.5	1.2	0.8
8.1	7.5	6.0	4.0	6.0	6.0	5.9
9.0	8.5	8.0	5.0	7.0	7.3	7.2
0.8	0.5	0.0	1.0	0.0	0.5	0.4
4.5	2.0	4.0	3.0	4.0	3.3	3.3
6.9	4.0	5.0	3.0	3.8	4.0	4.0
8.1	5.5	6.0	8.0	6.0	6.0	6.3
6.7	5.0	4.0	5.0	4.0	4.5	4.5
6.4	5.5	7.0	3.0	4.0	6.0	5.1
6.2	4.0	7.0	8.0	4.0	7.5	6.1
6.6	4.0	7.0	8.0	6.5	5.7	6.2
4.4	0.5	2.0	3.0	3.5	4.0	2.6
5.5	4.0	5.0	3.0	4.5	4.5	4.2
8.6	8.0	8.0	8.5	7.0	8.0	7.9
7.0	3.5	7.5	8.0	7.0	8.1	6.8
5.8	4.0	6.0	7.0	4.0	5.0	5.2
0.3	0.0	0.0	0.0	0.0	0.5	0.1
0.7	0.5	0.0	0.0	0.0	0.6	0.2
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.9	0.0	0.0	0.0	0.0	1.0	0.2
2.7	1.0	2.0	0.5	0.5	2.7	1.3
1.9	1.0	2.0	0.5	0.0	2.5	1.2
9.9	10.0	10.0	10.0	9.0	10.0	9.8
6.0	6.0	4.0	5.0	5.0	6.0	5.2
8.8	8.5	8.0	7.5	8.0	8.0	8.0
8.5	8.0	7.5	7.5	8.0	8.0	7.8
8.6	8.0	8.0	7.0	7.5	7.5	7.6
7.8	7.5	8.0	6.0	5.5	6.5	6.7
7.2	7.0	6.0	3.0	3.0	6.2	5.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.2	8.5	8.5	7.0	8.0	9.5	8.3
8.6	7.5	8.5	6.5	7.5	8.8	7.8
7.8	5.0	3.0	8.0	7.0	8.0	6.2
5.8	2.0	3.0	3.0	2.5	3.5	2.8
2.7	2.0	0.5	2.0	1.0	2.0	1.5
5.2	4.0	4.0	4.0	4.0	5.0	4.2
7.2	4.0	3.0	8.0	7.5	6.8	5.9
6.6	5.0	7.0	8.0	6.5	7.3	6.8
5.0	3.0	2.0	2.0	4.0	4.0	3.0
7.8	5.0	9.0	7.0	7.5	7.3	7.2
5.3	5.0	3.0	4.0	3.0	4.0	3.8
4.7	4.0	4.0	3.0	2.5	3.5	3.4
5.2	3.0	4.0	3.0	3.0	4.0	3.4
6.3	2.0	6.0	5.0	....	6.2	4.8
4.2	1.0	1.0	1.0	....	3.0	1.5
3.7	1.0	2.0	3.0	2.0	3.5	2.3

to the committee that a systematic investigation of the same pigments should be made under service conditions. The Paint Manufacturers' Association of the United States offered to erect a series of steel panels at Atlantic City and place them under the supervision and control of this Society. The panels were erected in the autumn of 1908."

The third annual inspection of the tests was made by members of the sub-committee on April 1, 1912, and the fourth annual inspection on April 16, 1913. In making the inspection, the usual system of ratings was followed, those paints which were giving the greatest protection from corrosion, presenting the best appearance and showing the greatest durability, being accorded the highest rating, No. 10, while those coatings which had entirely failed their intended purpose were given the rating No. 0. The intermediate ratings are indicative of the merits of the respective paints. The results of each inspection are given in Table I (Plate VIII), each inspector's rating for each paint being given, as well as the average rating of all the inspectors for each inspection.

Respectfully submitted on behalf of the sub-committee,

H. A. GARDNER,
Chairman.

SUPPLEMENTAL REPORT.

On account of the necessity of clearing the land, for building purposes, upon which now stands the steel test fence, an inspection of the panels was made on June 23, 1913, by the sub-committee to determine which panels should be reserved for future test. The paints which had failed in the test were marked for discontinuance. They are as follows: Nos. 1, 2, 3, 6, 7, 27, 28, 29, 30, 31, 32, 33, 45, 48, 222, 333, 777, 2000, 3000, 4000, 90, 100, 5555.

The panels facing the ocean on each of the three fences, representing the other paints, will be removed from the fence and placed for future exposure on Young's Million Dollar Pier, upon a test frame to be erected for the purpose. The expenses of the removal of the panels and their future installation will be met by an appropriation made by the Paint Manufacturers' Association of the United States.

H. A. G.

REPORT OF SUB-COMMITTEE E ON LINSEED OIL.

The sub-committee reports as follows:

After considering the reports of this sub-committee since its organization, it was decided to secure samples of oils pressed from seed grown in India and South America, to determine the specific gravity at 15°.5/15°.5 C., the iodine number, the saponification number, the acid number, and the refractive index on them, in order to ascertain whether these figures would fall within the limits of the tentative specifications recommended in 1909,[1] which were based on samples of North American oil. Accordingly, in addition to the samples already on hand, the following samples were secured:

Sample No.

16....Sample of linseed oil taken at the Atlantic Mill, National Lead Co., February 24, 1911, by A. H. Sabin. Bottled March 1, 1911. Argentine seed.

17....Sample of linseed oil taken at the Atlantic Mill, National Lead Co., by A. H. Sabin. Composite daily samples from August 25, 1911, to October 21, 1912, inclusive. Calcutta seed.

18....Sample of linseed oil taken at the Atlantic Mill, National Lead Co., by A. H. Sabin. Composite daily samples from October 23, 1911, to January 26, 1912, inclusive. Bombay seed.

19....Sample of linseed oil taken at the Atlantic Mill, National Lead Co., by A. H. Sabin. Composite daily samples from January 27, 1912, to March 30, 1912, inclusive. North American seed.

20....Sample of linseed oil taken at the Atlantic Mill, National Lead Co., by A. H. Sabin. Composite daily sample from April 1, 1912, to May 22, 1912, inclusive. North American seed.

21....Sample of linseed oil taken at the Atlantic Mill, National Lead Co., by A. H. Sabin. Composite daily samples from May 23, 1912, to June 24, 1912, inclusive. North American seed.

22....Sample of linseed oil taken at the Atlantic Mill, National Lead Co., by A. H. Sabin. Composite daily samples from June 27, 1912, to July 3, 1912, inclusive. Calcutta seed.

23....Sample of linseed oil taken at Spencer Kellogg & Sons, Hudson Heights, N. J., May 17, 1912, by a representative of the New York Federal Laboratory. South American seed.

28....Sample of linseed oil taken at the Dean Works, American Linseed Co., August 4, 1911, by a representative of the New York Federal Laboratory. Calcutta seed.

[1] *Proceedings*, Am. Soc. Test. Mats., Vol. IX, p. 164 (1909).

The samples were submitted to the members of the committee and several others, with the following circular letter in which the methods outlined are those of the 1909 report:

WORK OUTLINE FOR SUB-COMMITTEE E ON LINSEED OIL.

LINSEED OIL.

This committee has obtained a number of additional samples of linseed oil made from linseed of different origin which are ready to be sent out for testing.

Samples Nos. 17, 22, 28 are oil obtained from Calcutta seed. No. 18 is from Bombay seed, Nos. 16, 23 are from La Plata seed, and Nos. 19, 20, 21 from North American Seed. On these samples determine the specific gravity at 15°.5 C., the acid number, the iodine number (Hanus), the saponification number and the index of refraction, all by the methods given in report of the Sub-Committee on Linseed Oil in the proceedings of the Society for 1909.

With the results of this work will you please express your opinion on the advisability of including the Calcutta and Bombay oils with North American in a set of specifications, and whether you favor the drawing up of another set for oil obtained from South American seed.

Make also a hexabromide test. Samples Nos. 5, 6, 18, 20, and 23 are to be used for the determination of the hexabromides. We ask that you follow the method outlined herewith, but wish that if you are able to develop any modification which gives more reliable results, that you would report your findings.

Preparation of the free fatty acids:

"Boil 50 g. of the oil with 40 cc. of a solution of potassium hydroxide, specific gravity 1.4, and 40 cc. of alcohol in a porcelain dish on a water bath, with constant stirring until the soap becomes pasty. The soap is then dissolved in a liter of water and the solution boiled to evaporate the alcohol; this can be effected readily by replacing the water as it boils away. Next the soap is decomposed by means of diluted sulphuric acid. When by continued boiling the fatty acids have been obtained as a clear oily layer, free from solid particles floating on the aqueous liquid, the latter is drawn off by means of a siphon, and the fatty acids washed several times with hot distilled water until all the mineral acid has been removed. Since the fatty acids of lower molecular weight dissolve in hot water and may redden litmus paper, methyl orange should be used to test for the complete removal of the mineral acid. The dish containing the fatty acids is then placed on a water bath and warmed until the fatty acids are completely liquefied. The water and impurities will settle out, and the warm acids may then be poured through a dry plaited filter in a hot water funnel. The fatty acids thus obtained will be sufficiently dry for examination."

If time permits, prepare the fatty acids by Goldschmidt's method also, as follows, and then proceed with the determination:

"Boil 50 g. of the oil with 30 cc. of a solution of potassium hydroxide,

200 g. of KOH in 300 cc. of H_2O., and 70 cc. of alcohol in a porcelain dish on the water bath with constant stirring, until the soap becomes pasty. The soap is then dissolved in a liter of water and the solution boiled to evaporate the alcohol. Transfer the soap to a separatory funnel and decompose with dilute sulphuric acid; add 150 cc. of ether and shake. Draw off the aqueous layer and wash the other layer free from mineral acid, using a strong solution of sodium chloride instead of water for this washing. Transfer the ether solution to a wide mouth stoppered flask, cool to below 25° C., and add sufficient anhydrous sodium sulphate to thoroughly dry (generally from 35 to 50 g. will be sufficient). Insert stopper and let stand with frequent shaking, for about one hour. See that the temperature does not rise above 25° C. Filter through a dry paper into another flask and drive off the ether by a current of dry hydrogen at a temperature not above 50° C., which can be maintained by setting the flask in a bath of warm water."

To determine the percentage of hexabromides in the free fatty acids, take one gram of the sample and weigh into a stoppered flask, add 50 cc. of absolute ether, chill, add bromine drop by drop, being careful to keep the flask and contents between 4° and 6° C., until an excess of bromine is shown by a permanent reddish brown color. Let stand in water between 4° and 6° C. for thirty minutes, then filter and wash four times with 20 cc. of cold absolute ether. After the addition of the ether put the flask back into the ice water bath for a few minutes before filtering or centrifuging. Dry in a water bath, after the ether is removed continue drying for one hour and weigh. A centrifuge is of advantage if available.

P. H. Walker has found that after saponifying the oil from a paint, the iodine number of the oil is low, while that of the fatty acids from the same oil will be about normal. In view of this fact it is desirable to establish limits of the iodine value of the free fatty acids, so we ask that you determine it on the fatty acids prepared from the various oils.

BOILED OIL.

One of the requisites in dealing with this product is to have a definition. Will you not give us the benefit of your ideas on this subject, formulating a definition if possible, but at least letting us know what things you think ought to be included in the definition?

Samples Nos. 25, 27 and 29 are of the linoleate type, that is, the lead and manganese are combined with linseed oil alone. Nos. 24 and 26 are made by combining the lead and manganese with resin, and adding this resinate to the oil.

On these samples please determine the specific gravity, the iodine number (Hanus), the acid number, the saponification number, the percentage of ash and that of lead, calcium and manganese in the ash, and the unsaponifiable matter soluble in petroleum ether; if the time permits, also the percentage of hexabromides by the methods outlined for raw oil.

To determine the amount of lead, calcium and manganese, take 20 or more grams of the boiled oil and burn off in a silica or porcelain dish or dissolve out the lead and manganese in a separatory funnel with hydrochloric

or nitric acids. If ashing is followed, place the vessel on the floor of a hood, heat by an inclined flame until the oil burns. Remove the flame and allow the oil to burn as long as it will. Apply the inclined flame again until all of the volatile matter is consumed. Burn off the carbonaceous matter at as low a heat as possible; do not heat above a barely visible red. If convenient use a muffle. Dissolve the ash and make quantitative determinations of lead, manganese and calcium, describing methods used in reporting results.

GLENN H. PICKARD
Chairman.

The analysts so far reporting are as follows:

1. Dean M. Jackman for S. S. Voorhees, Bureau of Standards, Washington, D. C.
2. E. W. Boughton, Bureau of Chemistry, Contracts Laboratory, Washington, D. C.
3. S. Ginsburg for P. H. Walker, Chief of Contracts Laboratory, Washington, D. C.
4. C. B. Mills for G. W. Thompson, Chief Chemist, National Lead Co., 129 York St., Brooklyn, N. Y.
5. H. A. Crown for G. H. Pickard, Chemist, American Linseed Co., 11099 Torrence Ave., Chicago, Ill.
6. H. C. Mougey for D. A. Kohr, Superintendent of Lowe Brothers Co., Dayton, Ohio.
7. E. W. Martin, Chemist, Midland Linseed Products Co., Minneapolis, Minn.
8. A. H. Gill, Massachusetts Institute of Technology, Boston, Mass.
9. Wm. R. Eipper for E. C. Holton, Chemist, Sherwin-Williams Co., Cleveland, Ohio.

RESULTS OF TESTS ON RAW LINSEED OIL.

The results reported on raw linseed oil are given in Table I.

Samples Nos. 16 and 23, which are from South American seed, each have an iodine value lower than specification limits, and therefore indicate the impossibility of including North and South American oils in one specification.

The new samples of North American seed, from another year's crop, give results which fall within the tentative specifications proposed by the sub-committee.

Examination of these results shows that, like samples Nos. 1, 2, 3 and 4, sample No. 16 has changed but slightly during the two years which have elapsed since bottling.

The oils from Calcutta and Bombay seed give results which agree closely with those from North American seed, except

TABLE I.—RESULTS OF TESTS ON RAW LINSEED OIL.

SOUTH AMERICAN SEED.

SAMPLE NO. 16.

Analyst.	Specific Gravity at 15°.5/15°.5 C.	Acid Number.	Saponification Number.	Refractive Index at 25° C.	Iodine Number, Hanus.
1	0.9325	1.26	191.0	1.4786	171.8
2	0.9332	1.42	193.4	1.4784	170.5
3	0.9330	1.40	190.0	1.4779	170.6
4	0.9323	1.37	189.8	1.4788	171.8
7	0.9320	1.54	191.4	1.4789	171.8
8	.....	1.81	192.9	.....	168.1
Average	0.9326	1.47	191.4	1.4785	170.8

SAMPLE NO. 23.

1	0.9321	3.22	190.4	1.4787	173.2
2	0.9327	3.61	191.2	1.4784	171.6
3	0.9328	3.53	190.3	1.4773	172.8
4	.....	3.43	189.8	1.4787	171.9
5	0.9324	3.30	190.3	.....	172.9
6	0.9317	3.53	186.2	.....	174.5
7	0.9327	3.57	191.5	1.4788	174.9
8	.....	3.86	194.3	.....	168.9
9	0.9263[b]	3.77	190.6	.....	170.0
Average	0.9315	3.54	190.5	1.4784	172.3

NORTH AMERICAN SEED.

SAMPLE NO. 19.

Analyst.	Specific Gravity at 15°.5/15°.5 C.	Acid Number.	Saponification Number.	Refractive Index at 25° C.	Iodine Number, Hanus.
1	0.9356	1.68	191.3	1.4806	188.7
2	0.9360	1.76	194.4	1.4805	187.6
3	0.9360	1.64	189.8	1.4795	187.6
4	0.9346	1.65	190.2	1.4805	188.1
5	0.9355	1.51	191.2	.....	189.1
6	0.9353	1.68	192.6	.....	187.9
8	.....	2.08	195.3	.....	185.5
9	0.9308[a]	2.32	193.6	.....	185.6
Average	0.9355	1.79	192.3	1.4803	187.5

SAMPLE NO. 20.

1	0.9357	1.68	191.3	1.4805	188.9
2	0.9360	1.76	193.6	1.4806	185.8
3	0.9360	1.71	190.8	1.4791	187.5
4	0.9348	1.72	191.5	1.4803	187.5
5	0.9356	1.63	190.1	.....	185.7
6	0.9353	1.79	186.6	.....	189.0
7	0.9355	1.77	192.2	1.4811	188.6
8	.....	2.33	195.9	.....	186.1
9	0.9304[b]	2.37	195.0	.....	185.2
Average	0.9356	1.86	191.9	1.4803	187.1

SAMPLE NO. 21.

1	0.9353	2.38	191.4	1.4803	187.6
2	0.9357	2.52	192.4	1.4804	183.2
3	0.9354	2.47	190.8	1.4790	185.6
4	0.9345	2.45	190.9	1.4805	186.3
5	0.9350	2.27	190.7	.....	186.5
6	0.9353	1.52	187.3	.....	187.2
8	.....	3.08	194.8	.....	182.8
9	0.9297[b]	3.05	195.6	.....	184.1
Average	0.9352	2.47	191.7	1.4801	185.4

[a] Specific gravity taken at 25°.5/25°.5 C. This value not used in computing average.

[b] Specific gravity taken at 26°/26° C. This value not used in computing average.

TABLE I.—RESULTS OF TESTS ON RAW LINSEED OIL (*Continued*).

CALCUTTA SEED.

SAMPLE NO. 17.

Analyst.	Specific Gravity at 15°.5/15°.5 C.	Acid Number.	Saponification Number.	Refractive Index at 25° C.	Iodine Number, Hanus.
1	0.9332	1.26	191.2	1.4794	179.8
2	0.9337	1.32	193.4	1.4795	179.4
3	0.9341	1.24	190.1	1.4785	178.1
4	0.9325	1.26	192.1	1.4792	178.5
5	0.9333	1.09	191.1	.....	178.4
6	0.9335	1.24	189.8	.....	179.2
8	.....	1.43	195.3	.....	176.3
Average	0.9334	1.26	191.9	1.4792	178.5

SAMPLE NO. 22.

1	0.9333	1.82	191.2	1.4794	178.6
2	0.9338	2.07	191.9	1.4792	175.9
3	0.9341	2.00	191.7	1.4778	178.3
4	0.9323	1.94	190.9	1.4794	176.5
8	.....	2.25	194.8	.....	174.1
Average	0.9334	2.02	192.1	1.4790	176.7

SAMPLE NO. 28.

1	0.9327	1.54	190.8	1.4793	178.1
2	0.9328	1.75	192.0	1.4791	176.2
3	0.9334	1.67	190.0	1.4785	178.4
4	0.9320	1.60	191.7	1.4790	177.8
5	0.9326	1.57	189.9	.....	179.3
6	0.9345	1.72	196.4	.....	178.8
7	0.9329	1.76	192.0	1.4794	178.2
9	0.9278[b]	1.45	192.1	.....	175.6
Average	0.9330	1.63	191.9	1.4791	177.8

BOMBAY SEED.

SAMPLE NO. 18.

Analyst.	Specific Gravity at 15°.5/15°.5 C.	Acid Number.	Saponification Number.	Refractive Index at 25° C.	Iodine Number, Hanus.
1	0.9334	1.12	190.7	1.4796	179.8
2	0.9340	1.20	193.0	1.4795	179.6
3	0.9342	1.11	192.8	1.4787	178.6
4	0.9327	1.03	190.9	1.4795	178.9
5	0.9333	1.08	191.0	.....	180.8
6	0.9335	1.16	192.3	.....	181.4
7	0.9341	1.12	195.0	1.4797	181.7
8	.....	1.40	194.0	.....	177.3
9	0.9289[a]	1.78	193.8	.....	177.5
Average	0.9336	1.22	192.6	1.4794	179.5

[a] Specific gravity taken at 25°.5/25°.5 C. This value not used in computing average.
[b] Specific gravity taken at 26°/26° C. This value not used in computing average.

with respect to the iodine number, which is a little lower. Two of the samples have iodine numbers below the minimum of 178 set by the tentative specifications. These results make it necessary to lower the minimum of 178 to 176, or to state that the specifications apply to oils from North American seed only. The latter course seems more advisable, and the subcommittee therefore recommends that the tentative specifica-

tions proposed in 1909, with the exception that there be no maximum limit to the iodine number, be adopted as standard by the Society, under the title of "Standard Specifications for the Purity of Raw Linseed Oil from North American Seed." The recommended methods of testing for the specified properties given in the report for 1909 are included in the specifications, which are appended to this report.[1]

Hexabromide Precipitates.—Owing to the fact that it is possible to adulterate raw linseed oil with other vegetable oils

TABLE II.—PERCENTAGE OF HEXABROMIDES.

Sample No.	Analyst.	By Committee Method.	By Eibner's Method.
5	1	33.60	
	2	40.00	
	4	41.87	49.00
	5	37.04	48.80
6	1	35.60	
	2	39.00	
	4	44.45	48.51
	5	37.90	48.63
18	1	35.10	
	2	44.30	
	4	51.18	51.04
	5	37.90	50.70
20	1	34.60	
	2	46.30	
	4	48.84	52.20
	5	38.10	51.57
23	1	36.20	
	2	39.30	
	4	48.36	48.69
	5	34.20	48.49

to a considerable extent without detection, the sub-committee is also working to develop a test which will make this impossible. The determination of the hexabromides seemed to offer possibilities, so samples were sent out with the above circular letter outlining a method for the determination of the hexabromides on the free fatty acids of the oil. The results obtained in determining the hexabromides are given in Table II.

The obvious conclusion to be drawn from the results obtained by the use of the method outlined by the committee is that it is unreliable and must, therefore, be abandoned.

[1] In presenting these specifications the committee recommended the changes given on pp. 18–19. The specifications as amended appear on pp. 399–401.—ED.

We wish to draw especial attention to the results obtained by Mr. G. W. Thompson by the Eibner method for determining the insoluble hexabromides of linseed oil. Duplicates gave results agreeing very closely. In his report Mr. Thompson states that the method is, in his opinion, a most satisfactory one for this determination. This method is given in abstract at the end of this report (pages 393–398).

Your committee proposes to have this method used on other samples by several analysts during the coming year, in the hope that the results obtained will warrant our endorsement of the method and enable us to set limits for the percentage of insoluble hexabromides of pure linseed oil.

RESULTS OF TESTS ON BOILED LINSEED OIL.

The boiled oil samples tested are as follows:

Sample No.

24....Sample of boiled linseed oil, resinate type, taken at the Dean Works, American Linseed Co., July 16, 1912, by a representative of the New York Laboratory of the Bureau of Chemistry. North American seed.

25....Sample of boiled linseed oil, linoleate type, taken at the Dean Works, American Linseed Co., July 16, 1912, by a representative of the New York Laboratory of the Bureau of Chemistry. North American seed.

26....Sample of boiled linseed oil, resinate type (so described), taken at the works of the Archer Daniels Linseed Oil Co., Minneapolis, August 21, 1912, by a representative of the Minneapolis Laboratory of the Bureau of Chemistry.

27....Sample of boiled linseed oil, linoleate type, taken at the works of the Midland Linseed Products Co., Minneapolis, August 21, 1912, by a representative of the Minneapolis Laboratory of the Bureau of Chemistry.

29....Sample of boiled linseed oil, linoleate type, taken at the Atlantic Mill, National Lead Co., January, 1913, by A. H. Sabin.

The results obtained by the several analysts are given in Table III.

These results are interesting as showing figures which are of value in the consideration of specifications for boiled linseed oil, and are particularly gratifying in the general agreement of the determinations of ash and of lead, manganese, and calcium, showing that there are several good methods for these determinations as described in the individual reports given below.

TABLE III.—RESULTS OF TESTS ON BOILED LINSEED OILS.

SAMPLE NO. 24. RESINATE.

Analyst.	Specific Gravity at 15°.5/15°.5 C.	Iodine Number, Hanus.	Saponification Number.	Acid Number.	Refractive Index at 25° C.	Unsaponifiable Matter, Soluble in Petrolic Ether.	Ash, per cent.	Manganese, per cent.[1]	Lead, per cent.[1]	Calcium, per cent.[1]
1.....	0.9424	181.2	190.8	7.00	.....	0.360	0.354	0.0641	0.107	0.0192
2.....	0.9424	180.6	192.4	8.36	.....	1.113	0.370	0.0590	0.110	0.020
3.....	0.9429	181.6	192.5	8.04	1.4830[a]	0.920	0.350	0.0610	0.094	0.011
4.....	0.9413	179.8	190.1	8.01	1.4836	0.950	0.365	0.0693	0.106	0.025
5.....	.....	182.6	189.3	8.11	.....	.....	0.387	0.0680	0.105	0.016
7.....	0.9430	181.9	191.0	8.44	1.4826	.....	0.368	.....	.....	.....
Aver...	0.9422	181.3	191.0	7.99	1.4831	0.836	0.366	0.0642	0.104	0.018

SAMPLE NO. 25. LINOLEATE.

1.....	0.9471	178.1	191.1	5.32	.....	1.200	0.631	0.038	0.323	0.012
2.....	0.9468	182.2	193.3	6.34	.....	0.810	0.590	0.035	0.370	0.030
3.....	0.9473	180.2	193.2	6.30	1.4835[a]	0.740	0.620	0.041	0.330	0.019
4.....	0.9462	174.9	190.8	6.40	1.4829	0.790	0.678	0.046	0.392	0.035
5.....	.....	180.6	193.0	7.18	.....	.....	0.682	0.041	0.445	0.020
7.....	0.9488	177.2	192.0	6.51	.4853	.....	0.651	.....	.....	.....
Aver...	0.9472	178.9	192.2	6.34	1.4841	0.885	0.642	0.040	0.372	0.0232

SAMPLE NO. 26. RESINATE.

1.....	0.9359	183.4	184.2	6.16	.....	2.59	0.177	0.0255	0.055	0.015
2.....	0.9358	182.3	186.2	7.16	.....	4.39	0.170	0.0180	0.060	0.020
3.....	0.9358	184.6	185.7	6.90	1.4820[a]	4.31	0.210	0.0260	0.044	0.013
4.....	0.9348	182.0	187.7	6.73	1.4813	3.86	0.196	0.0329	0.071	0.017
5.....	.....	183.7	186.0	6.80	.....	....	0.197	0.0270	0.053	0.013
7.....	0.9359	182.6	184.4	7.05	1.4821	....	0.191	.....	.....	.....
Aver...	0.9356	183.1	185.7	6.80	1.4820	3.79	0.190	0.0259	0.0566	0.016

SAMPLE NO. 27. LINOLEATE.

1.....	0.9394	187.5	191.3	5.74	.....	0.15	0.225	0.046	0.055	0.008
2.....	0.9395	187.0	192.2	6.25	.....	0.90	0.200	0.035	0.060	0.030
3.....	0.9393	188.5	192.2	5.60	1.4820[a]	0.76	0.230	0.051	0.047	0.017
4.....	0.9381	185.1	192.9	5.69	1.4816	0.80	0.242	0.054	0.053	0.014
5.....	.....	187.9	191.9	5.88	.....	....	0.239	0.049	0.058	.....
7.....	0.9400	184.3	191.6	6.08	1.4870	....	0.236	.....	.....	.....
Aver...	0.9393	186.7	192.0	5.87	1.4843	0.65	0.228	0.047	0.055	0.017

SAMPLE NO. 29. LINOLEATE.

1.....	0.9439	180.1	190.4	4.34	.....	0.19	0.586	0.049	0.212	0.006
2.....	0.9436	179.4	190.5	5.67	.....	0.85	0.580	0.051	0.320	0.030
3.....	0.9438	181.9	192.2	4.57	1.4825[a]	0.73	0.580	0.051	0.270	0 025
4.....	0.9425	179.1	191.7	5.08	1.4822	0.62	0.591	0.055	0.339	0.024
5.....	.....	180.4	192.3	5.24	.....	.....	0.613	0.053	0.312	0.012
7.....	0.9452	180.0	194.3	5.08	1.4829	.....	0.593	.....	.....	.....
Aver..	0.9440	180.1	191.9	5.00	1.4825	0.597	0.590	0.0518	0.290	0.019

[a] These values are Refractive Index at 20° C. and are omitted from the averages.

[1] Calculated in some cases from oxides reported.

The following are individual reports from some of the analysts referred to above:

REPORT OF ANALYST 1.—DEAN M. JACKMAN.

MR. GLENN H. PICKARD, April 30, 1913.
Chairman, Sub-Committee E on Linseed Oil.

My dear Mr. Pickard:

I enclose tabulation (Tables IV, V and VI) of the results obtained on samples of boiled linseed oil sent with your letter of January 25. The methods used were in accordance with the instructions contained in the printed circular and require no special comment, except that as no muffle was available for ashing the oil, the final carbonaceous matter was burnt off over a Bunsen burner and it is probable that the results are somewhat low due to loss of lead.

TABLE IV.—CONSTANTS OF RAW LINSEED OILS, DETERMINED BY DEAN M. JACKMAN.

Source of Oil.	Sample No.	Lab. No.	Saponification Number.	Iodine Number, Hanus.	Acid Number.	Specific Gravity at		Refractive Index with Zeiss Butyro-refractometer at 25° C.
						15°.5 C.	25° C.	
La Plata.....	16	2202	191.0 191.1	171.0 172.4 172.0	1.40 1.12	0.9324 0.9325	0.9279 0.9278	1.4786
			191.0	171.8	1.26			
Calcutta.....	17	2203	191.3 190.9	179.9 179.8	1.40 1.12	..... 0.9332	0 9286 0 9286	1.4794
			191.1	179.8	1.26			
Bombay.....	18	2204	191.4 190.0	179.6 180.0	1.12 1.12	0.9334 0.9334	0 9288 0.9288	1.4796
			190.7	179.8	1.12			
North America	19	2205	191 2 191.5	188.4 189.1	1.68 1.68	0.9357 0.9355	0.9311 0.9309	1.4806
			191.3	188.7	1.68	0.9356	0.9310	
North America	20	2206	191.6 191.0	188.4 189 4	1.68 1.68	0.9356 0.9358	0.9309 0 9311	1.4805
			191.3	188.9	1.68	0.9357	0 9310	
North America	21	2207	191.8 191.0	187.3 188 3 187 2	2.52 2.24	0.9354 0.9352	0 9307 0.9307	1.4803
			191.4	187.6	2.38	0.9353		
Calcutta.....	22	2208	191.6 190.7	178.6 178.8 178.5	1.68 1.96	0.9334 0.9332	0.9288 0.9288	1.4794
			191.2	178.6	1.82	0.9333		
La Plata.....	23	2209	190.3 190.6	172.6 173.7 173.4	3.36 3.08	0.9322 0.9320	0.9275 0.9276	1.4787
			190.4	173.2	3.22	0.9321		
Calcutta.....	28	2214	190.5 191.0	178.1 178.2	1.40 1.68	..... 0.9327	0.9282 0.9281	1.4793
			190.8	178.1	1.54			

It is probable that such loss could have been avoided if muffle was employed and carbonaceous matter burnt off at a very low red heat. It was therefore necessary to determine lead on a 50-g. sample by boiling for an hour with a 10-per-cent solution of HCl and washing the oil several times with H_2O in a separating funnel.

On account of the small size of sample it was not possible to check this determination, but it is probable that one hour's boiling is not always sufficient to insure complete removal of all the metallic oxides.

It would be of great advantage if all the oxides could be determined in the ash and it is believed that this would be possible provided precautions are taken to prevent loss of lead.

I want to express my appreciation of the careful work done by Dean M. Jackman of this laboratory on all the samples of oil covered by this year's report. Very truly yours, S. S. VOORHEES.

TABLE V.—PERCENTAGES OF INSOLUBLE HEXABROMIDES, DETERMINED BY DEAN M. JACKMAN.

Sample No.	5	6	18	20	23
Laboratory No.	2200	2201	2204	2206	2209
Hexabromides Found	33.2	35.2	32.8	33.8	41.1
	33.9	36.1	37.5	35.3	31.4
	33.6	35.6	35.1	34.5	36.2

TABLE VI.—PROPERTIES OF BOILED LINSEED OIL, DETERMINED BY DEAN M. JACKMAN.

Sample No.	Lab. No.	Type of Oil.	Specific Gravity at 15°.5 C.	Iodine Number, Hanus.	Acid Number.	Saponification Number.	Ash, per cent.	Unsaponifiable Matter, per cent.	Metallic Oxides in Oil Determined: By Extraction with Acid. PbO, per cent.	By Extraction with Acid. CaO, per cent.	On Ash. Mn_3O_4, per cent.
24	2210	Resinate	0.9425	181.4	7.00	190.6	0.357	0.29	0.1123	0.0272	0.0876
			0.9423	181.1	7.00	191.1	0.351	0.44	0.1182	0.0266	0.0907
			0.9424	181.2	7.00	190.8	0.354	0.36	0.1152	0.0269	0.0891
25	2211	Linoleate	0.9471	177.7	5.32	190.8	0.631	0.19	.....	0.0105	0.054
			0.9471	178.6	5.32	191.4	0.632	0.05	0.348	0.0244	0.053
				178.1	5.32	191.1	0.6315	0.12	0.348	0.0174	0.053
26	2212	Resinate	0.9358	183.6	5.88	184.1	0.179	2.34	0.058	0.0232	0.035
			0.9359	183.2	6.44	184.2	0.175	2.84	0.061	0.0188	0.036
				183.4	6.16	184.1	0.177	2.59	0.060	0.0210	0.035
27	2213	Linoleate	0.9395	187.4	5.60	191.2	0.227	0.19	0.053	0.008	0.065
			0.9393	187.5	5.88	191.4	0.223	0.12	0.065	0.015	0.063
				187.4	5.74	191.3	0.225	0.15	0.059	0.012	0.064
29	2215	Linoleate	0.9439	180.4	4.20	190.2	0.588	0.18	0.239	0.005	0.069
			0.9439	179.9	4.48	190.6	0.585	0.21	0.219	0.013	0.069
				180.1	4.34	190.4	0.5865	0.19	0.229	0.009	0.069

REPORT OF ANALYST 2.—E. W. BOUGHTON.

METHODS USED FOR THE DETERMINATION OF LEAD, MANGANESE AND CALCIUM.

Twenty to thirty grams of oil were ashed at a dull red heat. The ash was dissolved in warm HNO_3 and H_2O_2. After cooling, about 25 cc. of 3-per cent H_2O_2 solution was added and a slight excess of NH_4OH. The solution was kept fairly cool, not above 35° C. The precipitated peroxides of lead and manganese were filtered off and washed, then dissolved in warm HNO_3 and H_2O_2, and the precipitation with H_2O_2 and NH_4OH repeated. After

TABLE VII.—REPORT OF WORK ON RAW LINSEED OILS, BY E. W. BOUGHTON.

Contract No.	Sample No.	Specific Gravity at 15°.5/15°.5 C. A = 50 cc. Plummet. B = 25 cc. Pyknometer.	Acid Number.	Iodine Number, Hanus.	Saponification Number.	Refractive Index at 25° C.
				173.1[a]		
15862	16	A.....0.9331	1.43	170.2	193.5	1.4780
		B.....0.9333	1.42	170.9	193.2	1.4788
		Aver.....0.9332	1.42	170.5	193.4	1.4784
15863	17	A.....0.9338	1.32	178.5	193.2	1.4790
		B.....0.9335	1.32	180.2	193.6	1.4800
		Aver.....0.9337	1.32	179.4	193.4	1.4795
15864	18	A.....0.9341	1.21	180.0	193.6	1.4792
		B.....0.9339	1.20	179.2	192.4	1.4798
		Aver.....0.9340	1.20	179.6	193.0	1.4795
15865	19	A.....0.9360	1.76	187.6	194.8	1.4800
		B.....0.9359	1.76	187.6	194.0	1.4810
		Aver.....0.9360	1.76	187.6	194.4	1.4805
15866	20	A.....0.9359	1.76	185.7	193.5	1.4801
		B.....0.9361	1.76	185.8	193.6	1.4810
		Aver.....0.9360	1.76	185.8	193.6	1.4806
15867	21	A.....0.9359	2.53	183.9	192.6	1.4800
		B.....0.9355	2.52	182.4	192.1	1.4808
		0.9357	2.52	183.2	192.4	1.4804
15868	22	A.....0.9340	2.08	175.2	192.3	1.4785
		B.....0.9336	2.06	176.6	191.6	1.4798
		Aver.....0.9338	2.07	175.9	191.9	1.4792
15869	23	A.....0.9327	3.62	171.4	190.8	1.4780
		B.....0.9326	3.60	171.8	191.6	1.4787
		Aver.....0.9327	3.61	171.6	191.2	1.4784
15874	28	A.....0.9335[a]	1.76	176.0	192.6	1.4786
		B.....0.9329	1.75	176.4	191.4	1.4796
		B.....0.9327				
		Aver.....0.9328	1.75	176.2	192.0	1.4791

[a] Omitted from average.

filtering and washing a second time, the filtrates were united, and the calcium precipitated therein as oxalate, then weighed as oxide as usual. The lead and manganese peroxides were dissolved on the filter and the solution made up to 250 cc. in a graduated flask. Two hundred cubic centimeters were pipetted out for lead determination, which was made by adding H_2SO_4, evaporating to fumes, finally weighing the $PbSO_4$ on a Gooch crucible as usual. Twenty-five cubic centimeters were pipetted out for manganese, which was determined by the bismuthate method. The separation with H_2O_2 and NH_4OH works nicely when considerable calcium is present. The amount of calcium in the present samples was so small that the lead could probably have been separated directly as $PbSO_4$, but the manganese would subsequently have to be removed. The advantage of the method lies in the fact that H_2S or $(NH_4)_2S$ is not used. Two precipitations are necessary, as some calcium is occluded.

TABLE VIII.—REPORT OF WORK ON IODINE NUMBERS AND HEXABROMIDE DETERMINATIONS ON FATTY ACIDS OF RAW LINSEED OIL, BY E. W. BOUGHTON.

Contract No.	Sample No.	Method of Precipitation of Fatty Acids.	Experiment No.	Iodine Number of Fatty Acids, Hanus.			Hexabromides of Fatty Acids, per cent.		
						Av.			Av.
15860	5	A	A-1	189.2	187.8	188.5	39.3	40.6	40.0
15860	5	B	B-1	186.1	187.5	186.8	39.0	38.4	38.7
15861	6	A	A-1	186.9	184.2	185.6	37.4	40.5	39.0
15861	6	B	B-1	184.2	182.4	183.3	35.5	34.8	35.2
15864	18	A	A-1	182.7[a]	181.6[a]	.....			
				187.9	190.0	189.0	43.5	45.1	44.3
15864	18	B	B-1	182.3[a]	183.1[a]	.....			
				188.9	189.4	189.2	32.3[a]	39.1	39.6
							40.1		
15866	20	A	A-1	195.0	193.8	194.4	45.9	46.6	46.3
15866	20	B	B-1	176.8	171.9	174.4			
		B	B-2	194.5	195.5	195.0	38.9	38.4	38.7
							43.5	41.1	42.3
15869	23	A	A-1	179.8[a]	170.5[a]				
				181.3	182.0	181.7	38.4	40.2	39.3
15869	23	B	B-1	168.2[a]	170.6[a]				
				174.2	172.5	173.4			
15869	23	B	B-2	173.6	176.3	175.0	41.4	36.9	39.2
		B	B-3	181.1[a]	189.2[a]				
				182.4	182.2	182.3	38.7	36.6	37.7

[a] Omitted from average; believed to be erroneous.

A—Oil saponified, fatty acids separated, boiled with distilled water until free from mineral acids, and filtered through filter paper.

B—Goldschmidt's method, using U. S. P. ether.

TABLE IX.—REPORT OF WORK ON BOILED LINSEED OIL, BY E. W. BOUGHTON.

Contract No.	Sample No.	Specific Gravity at 15°.6/15°.6 C.	Iodine Number, Hanus.	Acid Number.	Saponification Number.	Ash, per cent.	Lead, per cent.	Manganese, per cent.	Calcium, per cent.	Unsaponifiable Matter, per cent.		Resin Test.	
										Solvent Ether, U. S. P.	Petrolic Ether, 45°–60° C.	Liebermann-Storch Method.	Halpen and Hicks Method.
15870	24	0.9411[a]	180.5	8.30	205.4[a]	0.38	0.11	0.059	0.02	1.63	1.13	present	present
		0.9423	180.7	8.41	191.5	0.36	....	0.058	0.02				
		0.9425	.....	....	192.5	....	....	....	....				
		.....	.....	....	193.2	....	....	.....	....				
		Av. 0.9424	180.6	8.36	192.4	0.37	0.11	0.059	0.02				
15871	25	0.9469	176.3[a]	6.25	193.5	0.60	0.35	0.032	0.03	1.30	0.81	not detected	not detected
		0.9467	176.5[a]	6.42	193.1	0.57	0.38	0.037	0.03				
		.....	182.3	....	.....	....	....	.....	....				
		.....	181.9	....	.....	....	....	.....	....				
		Av. 0.9468	182.2	6.34	193.3	0.59	0.37	0.035	0.03				
15872	26	0.9364[a]	182.3	7.15	186.2	0.17	0.06	0.017	0.04	4.73	4.39	not detected	not detected
		0.9357	182.2	7.16	186.1	0.17	0.05	0.018	0.02				
		0.9359	.....	....	.....	....	....	.....	0.01				
		Av. 0.9358	182.3	7.16	186.2	0.17	0.06	0.018	0.02				
15873	27	0.9392	186.2	6.16	192.6	0.22	0.07	0.040	0.04	0.96	0.90	not detected	not detected
		0.9397	187.7	6.23	191.7	0.18	0.06	0.029	0.01				
		.....	.....	6.36	.....	....	....	.....	0 03				
		Av. 0.9395	187.0	6.25	192.2	0.20	0.06	0.035	0.03				
15875	29	0.9434	178.7	5.41	190.5	0.59	0.32	0.049	0.03	1.10	0.85	not detected	not detected
		0.9438	180.1	5.74	190.5	0.57	0.31	0.052	0.03				
		.....	.....	5.87	.....	....	....	.....	....				
		Av. 0.9436	179.4	5.67	190.5	0.58	0.32	0.051	0.03				

[a]Omitted from average; believed to be erroneous.

The figures for calcium are uncertain owing to the smallness of the samples. At least one quart should be sent to each analyst.

For the determination of unsaponifiable the Boemer method was followed, using one-fifth the prescribed quantities and omitting the second treatment with the alcoholic KOH. Where petrolic ether was used it was necessary to add alcohol to break up the emulsions.

REPORT OF ANALYST 3.—S. GINSBURG.

The figures for calcium, given in Table XI, are uncertain owing to the small size of the samples. The methods for the determination of the lead, manganese and calcium were the same as given in Mr. Boughton's report.

The unsaponifiable for boiled oils, Table XI, was determined by the Boemer method, using one-fifth the prescribed quantities and omitting the second treatment with alcoholic KOH. It was found necessary to use alcohol to break up the emulsions formed when petrolic ether was used as the extracting material.

It will be noted that the ratio of unsaponifiable extracted with ether to unsaponifiable extracted with petrolic ether = 1.54, 1.55, 1.53, and 1.59, respectively, in samples Nos. 24, 25, 27 and 29. This fact led to the determination of the unsaponifiable in a sample of commercial boiled oil.

The Boehmer method was followed exactly. When petrolic ether was used for the extraction, it was found necessary to add alcohol in order to break up the emulsions that formed.

ETHER EXTRACT, 100 GRAMS OF OIL.	PETROLIC ETHER EXTRACT, 100 GRAMS OF OIL.
1.05 per cent	0.65 per cent
1.07 "	0.68 "
Aver. = 1.06 "	Aver. = 0.67 "

$$\frac{\text{Ether Extract}}{\text{Petrolic Ether Extract}} = 1.58$$

Upon treatment of the unsaponifiable extracted by ethyl ether with petrolic ether it was found that white, flocculent residue remained undissolved.

TABLE X.—REPORT OF WORK ON LINSEED OILS, BY S. GINSBURG.

Contract No.	Sample No.	Specific Gravity at 15°.5/15°.5 C., 25-cc. Pyknometer.	Acid Number.	Iodine Number, Hanus.	Saponification Number.	Refractive Index at 25° C.
15862	16	0.9330	1.39	170.9	190.1	1.4779
		0.9329	1.41	170.3	189.8	
		Av.....0.9330	1.40	170.6	190.0	
15863	17	0.9339	1.23	177.9	190.2	1.4785
		0.9342	1.24	178.3	190.0	
		Av.....0.9341	1.24	178.1	190.1	
15864	18	0.9345	1.12	178.6	191.9	1.4787
		0.9338	1.09	178.6	193.6	
		Av.....0.9342	1.11	178.6	192.8	
15865	19	0.9357	1.61	187.4	189.7	1.4795
		0.9363	1.66	187.7	189.8	
		Av.....0.9360	1.64	187.6	189.8	
15866	20	0.9361	1.71	187.6	190.9	1.4791
		0.9359	1.71	187.4	190.6	
		Av.....0.9360	1.71	187.5	190.8	
15867	21	0.9354	2.48	185.2	191.5	1.4790
		0.9354	2.46	186.0	190.1	
		Av.....0.9354	2.47	185.6	190.8	
15868	22	0.9338	2.01	177.8	191.2	1.4778
		0.9343	1.99	178.8	192.2	
		Av.....0.9341	2.00	178.3	191.7	
15869	23	0.9330	3.49	173.1	190.6	1.4773
		0.9326	3.56	172.5	189.9	
		Av.....0.9328	3.53	172.8	190.3	
15874	28	0.9336	1.68	178.3	190.2	1.4785
		0.9332	1.66	178.4	189.7	
		Av.....0.9334	1.67	178.4	190.0	

TABLE XI.—REPORT OF WORK ON BOILED LINSEED OIL, BY S. GINSBURG.

Contract No.	Sample No.	Specific Gravity at 15°.6/15°.6 C.	Iodine Number, Hanus.	Acid Number.	Saponification Number.	Ash, per cent.	Lead, per cent.	Manganese, per cent.	Calcium, per cent.	Unsaponifiable, per cent.		Resin Test.		Refractive Index at 20° C.
										Soluble in Ether,	Soluble in Petrolic Ether, 45-60° C.	Liebermann-Storch Method.	Halpen and Hicks Method.	
15870	24	0.9428	181.3	8.05	192.0	0.35	0.096	0.064	0.011	1.42	0.92	present	present	1.4830
		0.9430	181.8	8.03	193.0	0.35	0.092	0.057						
		Av. 0.9429	181.6	8.04	192.5	0.35	0.094	0.061						
15871	25	0.9474	180.0	6.30	193.3	0.62	0.33	0.066[a]	0.019	1.15	0.74	not detected	not detected	1.4835
		0.9471	180.3	6.30	193.1	0.62	0.32	0.041						
		Av. 0.9473	180.2	6.30	193.2	0.62	0.33	0.041						
15872	26	0.9357	184.0	6.90	185.3	0.21	0.046	0.024	0.013	4.66	4.31	not detected	not detected	1.4820
		0.9359	185.2	6.90	186.1	0.21	0.041	0.027						
		Av. 0.9358	184.6	6.90	185.7	0.21	0.044	0.026						
15873	27	0.9392	189.0	5.60	192.2	0.23	0.042	0.054	0.017	1.16	0.76	not detected	not detected	1.4829
		0.9394	188.0	5.60	192.1	0.23	0.051	0.048						
		Av. 0.9393	188.5	5.60	192.2	0.23	0.047	0.051						
15875	29	0.9439	181.7	4.72	192.5	0.58	0.27	0.050	0.025	1.16	0.73	not detected	not detected	1.4825
		0.9437	182.1	4.42	191.8	0.58	0.27	0.051						
		Av. 0.9438	181.9	4.57	192.2	0.58	0.27	0.051						

[a] Omitted from average; believed to be erroneous.

REPORT OF ANALYST 4.—C. B. MILLS.

The method finally adopted for the determination of lead, manganese and calcium in boiled oils (Table XII) was to first get the oxides of the metals in the oil by ashing not less than 50 g. in a large porcelain dish, taking precaution to prevent any loss of lead by volatilization or the ash by dusting. Having gotten the ash practically free from carbon, the residue was treated with HCl and HNO_3 acids and the solution together with any insoluble matter was transferred to a small beaker, about 5 cc. one-to-one H_2SO_4 added and the solution taken to fumes of SO_3; allowed to cool and then diluted with water to about 100 cc. This warm solution was set aside for an hour or two and then 100 cc. of alcohol was added and the whole allowed to stand for one hour more. It was found by this treatment that the lead, free from calcium, could be easily and completely removed. The lead sulphate was dissolved in hot ammonium acetate to get rid of any SiO_2, etc., and the lead precipitated as chromate in filtrate, filtered and weighed in gooches as usual.

The filtrate from the insoluble sulphate, etc., containing the manganese and calcium, was diluted to 250 cc., and 100 cc. taken for manganese and 100 cc. for calcium.

TABLE XII.—RESULTS OF TESTS ON RAW AND BOILED LINSEED OILS, BY C. B. MILLS.

Oil No.	Iodine Number, Hanus.	Specific Gravity at 15°.5 C.	Acid Number.	Refractive Index at 25° C.	Saponification Number.
5	177.6	0.9317 (Check 0.9315)	5.44	1.4789	189.5
6	177.7	0.9326	2.31	1.4790	190.2
16	171.8	0.9323	1.37	1.4788	189.8
17	178.5	0.9325	1.26	1.4792	192.1
18	178.9	0.9327	1.03	1.4795	190.9
19	188.1	0.9346	1.65	1.4805	190.2
20	187.5	0.9348	1.72	1.4803	191.5
21	186.3	0.9345	2.45	1.4805	190.9
22	176.5	0.9323	1.94	1.4794	190.9
23	171.9	.9311–0.9312	3.43	1.4787	189.8
24 (Boiled)	179.8	0.9413	8.01	1.4836	190.1
25 (Boiled)	174.9	0.9462	6.40	1.4829	190.8
26 (Boiled)	182.0	0.9348	6.73	1.4819	187.7
27 (Boiled)	185.1	0.9381	5.69	1.4816	192.9
28	177.8	0.9320	1.60	1.4790	191.7
29 (Boiled)	179.1	0.9425	5.08	1.4822	191.7

TABLE XII (*Continued*).

Oil No.	Ash, per cent.	Mn, per cent.	Pb, per cent.	Ca, per cent.	Unsaponifiable Matter in Petrolic Ether, per cent.
24 (Boiled)	0.365	0.0693	0.1060	0.025	0.95
25 (Boiled)	0.678	0.0459	0.3920	0.035	0.79
26 (Boiled)	0.196	0.0329	0.0706	0.017	3.86
27 (Boiled)	0.242	0.0543	0.0529	0.014	0.80
29 (Boiled)	0.591	0.0556	0.3390	0.024	0.62

TABLE XIII.—HEXABROMIDE NUMBERS, BY C. B. MILLS.

BY COMMITTEE METHOD.[1]		BY "EIBNER'S METHOD."	
Oil No. 5	41.22 per cent	Oil No. 5	49.00 per cent
" " 5	43.18 "	" " 5	48.80 "
" " 5	41.55 "	" " 6	48.51 "
" " 5	41.56 "	" " 6	48.63 "
" " 6	44.45 "	" " 18	51.04 "
" " 18	51.18 "	" " 18	50.70 "
" " 20	48.84 "	" " 20	52.20 "
" " 23	48.36 "	" " 20	51.57 "
		" " 23	48.69 "
		" " 23	48.49 "

[1] Fatty acids prepared by first of two methods described in circular letter.

The manganese was determined by the Volhard method, the 100-cc. portion being checked by ashing another 50-g. sample and determining the manganese directly on the whole ash without first removing lead, etc. The results agreed satisfactorily.

The determination of calcium was carried out as follows:

The solution was made alkaline with ammonia and treated with H_2S for about one-half hour to precipitate the manganese, iron, etc. These sulphides were filtered off and the filtrate boiled until free from excess of ammonium sulphide; it was then made slightly acid with HCl and the remaining sulphides and free sulphur oxidized with bromine. In order to make sure that last traces of manganese were removed, the solution was made slightly alkaline with ammonia and again treated with bromine and filtered. The calcium was precipitated as oxalate in the usual way. The precipitate was ignited in platinum crucible, converted to sulphate, and weighed.

REPORT OF ANALYST 5.—H. A. CROWN.

Method of Ashing.—The sample, in a silica dish, was carefully heated by an inclined flame until the oil burned. The flame was removed and the oil allowed to burn as long as it would. The dish was then placed in the forward part of a gas muffle-furnace, heated to a dull red heat. When all the volatile matter was driven off, the dish was moved farther back in the muffle until all the carbonaceous matter was burned off. The ash was broken up with a platinum wire to insure complete combustion.

TABLE XIV.—RESULTS OF TESTS ON RAW LINSEED OILS.
(H. A. CROWN).

Sample No.	Iodine Number, Hanus.	Saponification Number.	Specific Gravity at 15°.5 C.	Acid Number.
17.....	178.4	191.1	0.9333	1.09
18.....	180.8	191.0	0.9333	1.08
19.....	189.1	191.2	0.9355	1.51
20.....	185.7	190.1	0.9356	1.63
21.....	186.5	190.7	0.9350	2.27
23.....	172.9	190.3	0.9324	3.30
28.....	179.3	189.9	0.9326	1.57

TABLE XV.—RESULTS OF TESTS ON FREE FATTY ACIDS.
(H. A. CROWN).

From Sample No.	Hexabromides.	Iodine Number, Hanus.
5.....	37.04	187.1
6.....	37.90	184.4
18.....	41.17	185.8
20.....	38.10	194.8
23.....	34.20	178.3

Determination of Manganese.—Separate portions of about 30 g. of the oil were ashed as above outlined. The ash was dissolved in nitric acid, specific gravity 1.135, to which a little 3-per-cent hydrogen peroxide was added. This dissolves the ash completely and quickly. The solution was boiled to expel the excess peroxide, cooled and then diluted with water to 250 cc. For the determination of manganese, 50-cc. portions were taken, to which 15 cc. of concentrated nitric acid was added, making a nitric acid solution of approximately 1.135 specific gravity. From this point, the sodium bismuthate method was followed exactly as given in Blair's *Chemical Analysis of Iron*, Seventh Edition.

Determination of Lead and Calcium.—For the determination of lead and calcium, larger portions of the oil were taken, at least 50 g. The ash was dissolved in nitric acid and hydrogen peroxide as in the case of the determination of managense, the entire solution being used for the determinations. Five cubic centimeters of concentrated sulphuric acid were added to the ash solution, which was then evaporated to white fumes. After cooling, about

TABLE XVI.—RESULTS OF TESTS ON BOILED LINSEED OILS (H. A. CROWN).

Sample No.	Iodine Number, Hanus.	Saponification Number.	Acid Number.	Percentage of			
				Ash.	Manganese.	Lead.	Calcium.
24.....	182.6	189.3	8.11	0.387	0.068	0.106	0.020
25.....	180.6	193.0	7.18	0.682	0.041	0.445	0.016
26.....	183.7	186.0	6.80	0.197	0.027	0.053	0.018
27.....	187.9	191.9	5.88	0.239	0.049	0.058	0.028
29.....	180.4	192.3	5.24	0.613	0.053	0.031	0.017

200 cc. of 50-per-cent alcohol was added and allowed to stand for 2 or 3 hours. Then the lead sulphate was filtered off and the filtrate saved for the determination of calcium. The washed precipitate was then dissolved in hot ammonium acetate, heated to boiling and the lead precipitated as chromate. The precipitate was collected in an alundum crucible, gently ignited and weighed.

The filtrate containing the calcium was made alkaline with ammonium hydroxide and the hot solution treated with hydrogen sulphide. The precipitated sulphides were filtered off, the filtrate boiled to expel the excess of ammonium sulphide, and then made acid with HCl and bromine added to oxidize the free sulphur. The solution was then made alkaline with ammonium hydroxide and the calcium precipitated from the boiling solution as oxalate.

NOTE.—Separate portions for manganese were taken because the muffle was too small to ash a larger quantity at one time. Where a large enough quantity can be ashed at one time, only one solution need be made for all three determinations, aliquot portions being taken.

REPORT OF ANALYST 7.—E. W. MARTIN.

June 19, 1913.

MR. G. H. PICKARD,

Chairman, Sub-Committee E on Linseed Oil.

Dear Sir:

We submit herewith our report on the samples of raw and boiled linseed oil received from your committee for analysis:

TABLE XVII.—RESULTS OF TESTS BY E. W. MARTIN.

Sample No.	1. Specific Gravity.		2. Turbidity and Foots, per cent.	3. Breaking Tests.	4. Moisture and Volatile Matter, per cent.		5. Ash, per cent.
	At 15°.5 C.	At 25° C.			Loss.	Gain.	
5	0.9324	0.9282	Trace	No Break	0.140	.....	0.068
6	0.9342	0.9297	2.34	Break	0.145	.....	0.154
16	0.9320	0.9281	1.00	Break	0.075	.....	.....
18	0.9341	0.9298	Trace	No Break	0.051	.....	0.132
20	0.9355	0.9315	Trace	Break	0.146	.....	0.174
23	0.9327	0.9285	3.61	Break	0.046	.....	0.103
24	0.9430	0.9382	0.25 Very turbid	No Break	.....	0.521	0.368
25	0.9488	0.9454	0.25 Very turbid	No Break	.....	0.366	0.651
26	0.9359	0.9313	1.47	No Break	.....	0.50	0.191
27	0.9400	0.9358	0.85	No Break	.....	0.43	0.236
28	0.9329	0.9284	3.40	No Break	0.064	.....	.....
29	0.9452	0.9409	0.35	No Break	.....	0.651	0.593

In Table XVII are given the results of the tests for specific gravity, turbidity and foots, breaking tests, moisture and volatile matter, and ash.

1. The specific gravity was determined with a 25-cc. gravity bottle. It has an attached thermometer and was standardized with pure water at 15°.5 C. and at 25° C.

2. The tests for turbidity and foots were run on 50-cc. samples in tall form water-comparison tubes.

3. The breaking tests were made in a test tube, heating by direct flame.

4. The moisture and volatile matter was determined in an air oven heated by a gas flame but maintained at 100° C.

5. Ash—no comments.

In Table XVIII is given the percentage of oxgyen absorption, using 10 g. of PbO passing through a 100-mesh screen.

In Table XIX are given the acid number, saponification number, the Liebermann-Storch test, refraction index at 25° C., and the iodine number.

You will note that the oxygen absorption on the various samples does not correspond with the iodine values of the same samples. We attribute this to an unevenness in the quality of the PbO in the oxygen absorption test, which we obtained from a sample we had in our laboratory, and to the fact that the distribution of the oil over the PbO was not uniform. We did not

TABLE XVIII.—RESULTS OF TESTS BY E. W. MARTIN.

Sample No.	Oil.	Amount Taken, grams.	Increase in per cent in — hours.							
			8	24	31	48	56	74	96	105
5	Raw	0.6200	0.20	11.42	11.71	12.00	12.00	12.24	12.35	12.10
6	"	0.6685	0.63	11.84	12.60	12.89	12.90	13.13	13.22	12.90
16	"	0.6226	0.33	7.71	11.86	13.30	13.50	13.64	13.53	.....
18	"	0.6975	0.64	11.74	14.12	14.76	14.92	15.08	15.00	.....
20	"	0.6164	0.37	11.61	14.71	15.91	16.04	16.07	15.91	.....
23	"	0.6620	1.34	11.88	13.96	14.16	14.06	.....	.....	.....
24	Boiled	0.7359	8.73	9.81	10.32	10.77	10.79	11.41	11.71	11.67
25	"	0.6400	8.48	9.62	10.04	10.50	10.67	11.14	11.33	11.28
26	"	0.6218	11.94	12.77	13.08	13.41	13.49	13.70	13.88	13.69
27	"	0.7300	10.17	11.31	11.80	12.26	12.42	12.81	13.11	12.94
28	Raw	0.6922	0.44	12.04	13.24	13.76	13.66	.....	.....	.....
29	Boiled	0.7094	8.06	9.43	9.92	10.43	10.70	11.23	11.58	11.51

TABLE XIX.—RESULTS OF TESTS BY E. W. MARTIN.

Sample No.	Acid Number.	Saponification Number.	Liebermann-Storch Test.		Refrac-Index at 25° C.	Iodine Number (Hanus).
			Resin.	Appearance.		
5	5.61	191.4	0	Green	1.4795	177.6, 177.4
6	2.36	192.4	0	Brown and Yellow	1.4796	180.2, 180.3
16	1.54	191.4	0	Green	1.4789	171.8, 171.7
18	1.12	195.0	0	Green	1.4797	181.4, 182.0
20	1.77	192.2	0	Green	1.4811	188.5, 188.6
23	3.57	191.5	0	Green	1.4788	175.0, 174.7
24	8.44	191.0	very strong	Violet to Brown	1.4826	181.9, 181.8
25	6.51	192.0	0	Brown	1.4853	176.9, 177.5
26	7.05	184.4	weak	Violet to Brown	1.4821	182.5, 182.7
27	6.08	191.6	0	Brown	1.4870	184.1, 184.6
28	1.76	192.0	0	Green	1.4794	178.2, 178.2
29	5.08	194.3	0	Brown	1.4829	180.4, 179.6

test out all of the samples because some of them were not large enough for our purpose, and we omitted some of the determinations because of lack of time to complete them.

These tests were made by our chemist, Mr. E. W. Martin.

Yours very truly,

MIDLAND LINSEED PRODUCTS CO.
E. C. BISBEE,
Vice-President.

Note by Mr. Pickard: These results are from the tests called for in the 1909 report of our committee. See *Proceedings*, Vol. IX, pp. 141 ff. (1909).

EIBNER'S METHOD.[1]

Description of New Method for Determination of Hexabromide Number of Linseed Oil Fatty Acids.

The determination of the hexabromide number is preceded by the preparation of free fatty acids.

1. *Preparation of Pure Linseed Oil Fatty Acids.*—Three and one-half grams of the linseed oil are weighed into each of three round-bottom evaporating dishes of about 220-cc. capacity, Then, 45 cc. of one-half-normal alcoholic potash are added in each case and the dishes are placed on the water bath. This is brought slowly to boiling. The oil is frequently stirred with a glass rod, flattened at the end. By this method, the saponification is better and more quickly accomplished.

The alcoholic potash is prepared as follows: 28 g. of solid pure caustic alkali are placed in a 1-liter measuring cylinder and dissolved in from 30 to 40 cc. of distilled water; then, 97-per-cent ethyl alcohol is added, to make the volume 1 liter. The solution is allowed to stand for 2 or 3 days to settle out any cloudiness due to potassium carbonate. This potash solution is best kept in a brown bottle, stoppered with a rubber stopper.

The water bath is not warmed until the evaporating dishes are filled. The saponification process begins slowly and gradually, so that the alcoholic soap solution does not crawl up to the rim of the evaporating dishes, thereby causing losses. The contents of the dishes are evaporated to dryness, with constant stirring and breaking up of the nearly dry soaps. In this way, the alcohol is completely removed. This whole operation of saponification and evaporation will take from 1 to 1½ hours. The resulting product will be a light yellow, agreeable smelling soap powder. The soap which first comes to dryness is mixed with 50 cc. of hot water, and dissolved on the boiling water bath. This requires about 5 minutes. This soap solution is added to the soap which next comes to dryness, and the first evaporating dish is rinsed out with water. Finally, this solution is added to the soap which last comes to dryness. The whole soap solution is cooled off somewhat and poured into a 1-liter separatory funnel, graduated at 180 cc. and 340 cc. The volume of the soap solution must now amount to 180 cc. and must not be any greater. The light yellow soap solution, which is absolutely clear in a warm state, is now cooled down to the temperature of tap water, whereby it becomes slightly cloudy. By the addition of 20 cc. of five-normal sulphuric acid, the linseed fatty acids are freed, and float on top of the liquid. They have an agreeable, characteristic odor and are, in the beginning, precipitated in an opaque, white form. After a few seconds, the emulsion disappears. The acids then are plainly yellow. The contents of the separatory funnel are now thoroughly shaken with 140 cc. of ether (second mark at 340 cc.), during which operation

[1]Translation of part of Eibner's article in the *Farben-Zeitung*, November 23, 1912 (No. 8).

the cock is opened at least once to avoid excessive pressure. After 5 minutes, the aqueous solution is drawn off as much as possible, the yellow ether solution of fatty acids is gently rotated and allowed to stand for a minute. After this operation, a little more water will settle in the lower part of the separatory funnel, and is removed. After adding 70 g. of anhydrous Glauber's salt, the fatty-acid solution is allowed to stand over night in the separatory funnel.

The detailed operation is as follows: Saponification should not be started until the afternoon. After setting free the fatty acids with sulphuric acid, 100 cc. of ether are first used for shaking out and allowed to stand. The aqueous solution is drawn off into a second separatory funnel, and then shaken out again with 40 cc. of ether. The combined ether solutions of fatty acids are then to be further treated as mentioned above.

The next forenoon, the recovery of the pure fatty acids is undertaken. For this purpose, a tared Erlenmeyer flask of 200-cc. capacity is used. The flask is stoppered with a well-pressed, two-holed, cork stopper. In one of the holes is inserted a 50-cc. dropping funnel, which supports an ordinary small funnel. In the other hole is placed a glass tube of 0.5-cm. bore, bent at a right angle, and this is connected with a Liebig condenser.

The dried ether solution of fatty acids is now filtered through a dry, folded filter (d = 18.5 cm.) into a 150-cc. Jena Erlenmeyer flask and from there is poured into the dropping funnel. Then about 100 cc. of this solution are run into the 200-cc. flask and the water bath is slowly warmed to about 70° C. As the ether is distilled off, more of the solution is added, drop by drop. The distilled ether is used to extract the Glauber's salt in the separatory funnel, which has absorbed a considerable amount of fatty acids. This is done six times, using from 100 to 120 cc. of ether each time. The fifth extraction is, as a rule, entirely colorless. Finally, by means of an ether wash-bottle, the folded filter, the flask used to receive the filtrate, the small funnel, and the dropping funnel are rinsed off, in order to recover quantitatively the fatty acids adhering to them. After the largest part of the ether is distilled off, the water bath is brought to boiling, and a few more cubic centimeters of ether will then be distilled off.

The extraction of the Glauber's salt and the distilling off of the ether take about 1½ hours. Even after ether has ceased to distill over, the fatty acids still contain some of it. Next, the flame of the water bath is extinguished, the Liebig condenser and dropping funnel are removed, and a tight-fitting stopper, with gas inlet and outlet tubes, is inserted in the flask. The end of the former tube is placed 1 cm. above the surface of the fatty acids. The outlet tube is drawn out to a capillary to prevent the hydrogen gas, which circulates above the fatty acids, from escaping too quickly, and to force it to mix with the ether vapors before leaving the flask. The hydrogen is first purified by passing it through an alkaline lead salt solution and then through concentrated sulphuric acid. The flask is replaced on the water bath, which is kept boiling vigorously. In order to drive off the ether, two hours are required. From four to five gas bubbles per second should pass through the flask. Experiments made with carbon dioxide instead of hydrogen give the same results, but we prefer to use hydrogen. Next, the fatty acids

are removed from the water bath, and, with a clean cloth, the hot flask is wiped off on the outside and inside around the top of the neck; then, while warm, it is put in a vacuum desiccator. This is evacuated to a high degree and then left standing for at least 4 hours. By this means, the fatty acids, as a rule, become partly solid. They are then weighed very quickly and put in a vacuum as before. After 2 hours, the flask is again weighed as quickly as possible, the weights having previously been put on the balance. Finally, the desiccator with flask is once more evacuated, and left standing over night. The next morning, the weight of the flask is checked.

2. *Preparation of the 10-per-cent Ether Solution of Fatty Acids.*—From the 9 to 10 g. of weighed linseed oil fatty acids, a 10-per-cent ether solution is now made. Forty cubic centimeters of ether, dried over calcium chloride, are added to the fatty acids, and carefully shaken until the latter are dissolved. This solution is poured quantitatively into an accurately graduated 100-cc., glass-stoppered, measuring cylinder, the graduation marks of which run half way around the circumference of the cylinder, whereas those for every 10 cc. run entirely around the cylinder. By means of an ether wash-bottle, the empty flask is washed with 20 cc. of ether, well shaken, and this liquid also is poured into the cylinder. The flask is then rinsed again, and care is taken to wash off whatever ether solution has run down on the outside. Then the cylinder is filled up nearly to the 100-cc. mark and shaken. The glass stopper is raised for a moment, and, after a minute, the cylinder is filled to the mark and thoroughly shaken once more. The lower meniscus is read.

3. *The Brominizing Process.*—By means of a standardized pipette, marked at the top and bottom, 20 cc. of the freshly shaken fatty-acid solution are removed from the graduated cylinder and placed in a 100-cc. Jena Erlenmeyer flask with not too narrow a neck. This 20 cc. should contain from 1.9 to 2.0 g. of fatty acids. A cork stopper, with a groove cut in the side, is placed in the flask, and then the latter is put in a cooling mixture of a temperature not exceeding $-10°$ C. This mixture is prepared in a suitable vessel, such as a water bath, by mixing finely broken ice with the necessary quantity of salt, and thoroughly stirring the mixture with a strong glass rod. In winter, snow can be used. The cooling mixture must be so made that the flask can be easily moved in it. After leaving the ether solution in the cooling mixture for 10 minutes, it will have the desired temperature. In the meantime, 1 cc. of commercial bromine is placed in the brominizing burette. A 10-cc. burette, or even a smaller one, is the most suitable, but the glass cock must be well ground in, and the delivery point must be fine. Before brominizing, the flask containing the fatty-acid solution must be shaken slowly in the cooling mixture. Five-tenths cubic centimeter of bromine—half of the quantity to be used—is added in single drops, and then the other 0.5 cc. of bromine, in double drops, keeping the flask cold throughout the operation by carefully shaking it in the cooling mixture. The detailed method of procedure is as follows: The cock of the burette is slowly opened, permitting a single drop of bromine to run down the side of the flask, thereby preventing loss by spattering. The cock of the burette is then closed, and the flask is shaken in the cooling mixture. After from 12 to 15 drops of bromine have been added in this manner, the hex-

abromide of linolenic acid generally begins to precipitate in the form of a fine crystalline powder, which settles quickly. With every additional drop, the precipitate can be plainly seen to increase. After 0.5 cc. of bromine has been added in single drops, which should take approximately 20 minutes, the other 0.5 cc. is added in double drops in exactly the same manner. This will take 10 minutes, so that the entire brominizing process will consume 30 minutes. After cooling for 2 minutes longer, the flask is again shaken and then allowed to stand stoppered for 2 hours in the cooling mixture. Over the precipitate can be seen a reddish brown fluid, a proof of the excess of bromine in the reaction mixture. Quite frequently, it is observed that some of the precipitate adheres to the sides of the flask, due perhaps to the intense cooling. This, however, cannot be avoided, and does not influence the quantitative recovery of the precipitated hexabromide. The time for brominizing, 30 minutes, must be strictly adhered to and must not be shortened. The added bromine disappears almost immediately, until an excess has been added. During the 2-hours standing, the temperature may rise somewhat, but in order to avoid secondary reactions as far as possible, it should never exceed $-5°$ C. In the meantime, the washing ether is prepared. Five cc. of ether are put in each of 5 test tubes, which are stoppered and set in the cooling mixture. For filtering, a Daniel filtering tube is used, which is provided with an asbestos pad, made as thin and uniform as possible. Two grams of Kahlbaum's asbestos, suspended in 500 cc. of water, will be sufficient for a series of determinations. On top of the asbestos a perforated porcelain plate is placed, the diameter of which must be almost as large as the inside diameter of the filtering tube. The perforated plate has about 20 round openings, 2 mm. in diameter. One liter of distilled water is drawn slowly through the tube, and the latter, with its cover, is then dried for one hour at 110° C., allowed to cool for an hour in the desiccator, and then weighed. In weighing, the tube is suspended by an aluminum wire. After the bromide precipitate has stood for 2 hours in the cooling mixture, it is filtered. The tared filtering tube is connected with a filtering flask, which, however, during the whole filtering process, is not connected with the pump. After making sure once more that the cooling mixture is at the proper temperature, the operator removes the flask containing the hexabromide and wipes it off with a dry cloth, without disturbing the precipitate. With the assistance of a glass rod, and without disturbing the precipitate, the mother-liquor is now carefully poured upon the filter and allowed to drain through completely. In the meantime, the precipitate is thoroughly shaken with the first 5-cc. portion of washing ether and left to settle in the cooling mixture. The ether becomes reddish brown; the precipitate becomes lighter. Immediately after the mother-liquor has run through the filter, the washing liquid in the flask is poured upon the filter, care being taken, however, to retain all the precipitate in the flask. The filter must never become dry, as this would cause a considerable delay in filtering.

The precipitate is then thoroughly mixed with the second 5-cc. portion of ether and brought, as completely as possible, upon the filter, immediately

after the first portion of washing ether has drained through. The precipitate settles immediately, and above it is a yellow solution which filters easily.

The flask is then cleaned with a feather, using the third 5-cc. portion of ether. Next, the precipitate still remaining in the flask is stirred up and brought upon the filter immediately after the preceding washing liquid has drained through. Then, the precipitate on the filter is stirred with a glass rod and is thus freed as much as possible from the mother-liquor. At this point, the washing ether, filtering through, still has a yellowish color, but the precipitate is almost white. The flask is again cleansed with the feather, using the fourth portion of ether. The latter, which is then colorless and contains only a trace of precipitate, is also poured upon the filter, in such a way as to rinse the rim of the filtering tube, up to which some of the mother-liquor has crawled during filtration. The precipitate on the filter is once more stirred up with the glass rod. The ether filtering through is now, in most cases, very faintly yellowish or colorless. Then the last 5-cc. portion of ether is used to rinse the flask once more. The glass rod is now cleaned with the feather, and the entire contents of the flask are brought upon the filter and allowed to run through. Then, with the filtering tube half covered, the filtering flask is connected with the suction pump, and the latter is worked strongly for one minute. The hexabromide shrinks to a very nice white mass. Occasionally, cracks occur in the precipitate. A small quantity of a slightly yellowish fluid is drawn from the bromide by the suction process, and the lower part of the filtering tube often becomes somewhat clouded with a small amount of residue left after the washing ether has evaporated. The filtering tube is now removed from the filtering flask, wiped off outside, and heated in a drying oven for 2 hours at from 80 to 85° C. Then it is allowed to cool for 1 hour in the desiccator and is weighed. It has often been observed that a hexabromide, which would be snow white in color, if dried at 80° C., becomes gray on the surface, if dried at 100° C. During filtration, especially during the first half of it, the precipitate must never become dry. Should this happen before the hexabromide is thoroughly pure, it can hardly be washed out completely, as sticky substances, bromides of various compositions, which, once dried, are difficult to dissolve in ether, adhere to the original precipitate. Before drying, the precipitate must be white, inside and out. If it shows a yellow color anywhere, it will partially melt during the drying process and become gray on the surface. The weight will then be somewhat too high. The filtering, as a rule, takes from 10 to 15 minutes and should not, at all events, exceed 25 minutes. The condition of the asbestos greatly influences the period of filtration. The hexabromide number is obtained by calculating the weight of hexabromide per 100 g. of fatty acids.

The hexabromide method is now so accurate that the hexabromide numbers of the fatty acids obtained by two separate saponifications of the same linseed oil check within 1 per cent. For two determinations run on the same fatty acid solution, the maximum difference is not more than 0.6 per cent. This accuracy is sufficient, as this is a complicated method involving many operations. All determinations by this method with various linseed oils have given very satisfactory results. For instance, with two different

saponifications of the same oil, the maximum difference was only 0.7 per cent. For the purpose of control, we had the hexabromide number of a linseed oil determined by disinterested parties. An average of 54.10 per cent was found. Two weeks later, we had the hexabromide number of the same linseed oil determined again, and this time the result was 54.21. Two determinations on the same linseed oil gave, as an average, a hexabromide number of 53.66.

It is important, for technical work, to obtain analytical results as quickly as possible. Consequently, we tried to make the hexabromide method more rapid without sacrificing its accuracy.

We saponified the linseed oil in the morning in the usual manner, prepared the ether solution of fatty acids, and let it stand over the Glauber's salt until three in the afternoon (4 to 5 hours). Then the fatty acids were freed from ether and treated with hydrogen for 2 hours. The pure fatty acids were left over night in a highly evacuated desiccator. By quickly weighing in the morning, the weight of acids was ascertained, and then we began the determination of the hexabromide number, so that the result was obtained during the afternoon. In the meantime, the iodine number and saponification number could have been determined, and also a qualitative test could have been made. So a pure linseed oil could be analyzed within two days, excepting in cases where the oil is to be tested for rape seed oil, in which case the separation and identification of erucic acid become necessary. Saponification could also be started in the afternoon, giving the ether solution of fatty acids a chance to stand over night with anhydrous Glauber's salt. The next day, the free fatty acids could be left in the desiccator until afternoon, but at least four hours should be allowed.

Respectfully submitted on behalf of the sub-committee,

GLENN H. PICKARD,
Chairman.

[NOTE.—The proposed Standard Specifications for the Purity of Raw Linseed Oil from North American Seed as amended (see pp. 18-19) were adopted by letter ballot of the Society on August 25, 1913, and follow the report of this sub-committee.—ED.]

AMERICAN SOCIETY FOR TESTING MATERIALS

PHILADELPHIA, PA., U. S. A.

AFFILIATED WITH THE

INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

STANDARD SPECIFICATIONS

FOR

THE PURITY OF RAW LINSEED OIL FROM NORTH AMERICAN SEED.

ADOPTED AUGUST 25, 1913.

I. PROPERTIES AND TESTS.

Properties.

1. Raw linseed oil from North American seed snall conform to the following requirements:

	Maximum.	Minimum.
Specific Gravity at $\frac{15°.5}{15°.5}$ C.	0.936	0.932
or		
Specific Gravity at $\frac{25°}{25°}$ C.	0.931	0.927
Acid Number	6.00	....
Saponification Number	195	189
Unsaponifiable matter, per cent	1.50	....
Refractive Index a 25° C.	1.4805	1.4790
Iodine Number (Hanus)	....	178

METHODS OF TESTING.

Methods of Testing.

2. The recommended methods of testing are as follows:

General.—All tests are to be made on oil which has been filtered at a temperature of between 60° and 80° F. through

paper in the laboratory immediately before weighing out. The sample should be thoroughly agitated before the removal of a portion for filtration or analysis.

Specific Gravity.—Use a pyknometer, accurately standardized and having a capacity of at least 25 cc., or any other equally accurate method, making a test at 15°.5 C., water being 1 at 15°.5 C., or a test at 25° C., water being 1 at 25° C.

Acid Number.—Expressed in milligrams of KOH per gram of oil. Follow the method described in Bulletin No. 107, revised 1908, Department of Agriculture, Bureau of Chemistry, page 142.

Saponification Number.—Expressed as with Acid Number. Blanks should also be run to cover effect of alkali in glass. Follow method given in Bulletin No. 107, revised 1908, Department of Agriculture, Bureau of Chemistry, pages 137–138.

Unsaponifiable Matter.—Follow Boemer's method taken from his Ubbelohde Handbuch Der Ole u. Fette, pages 261–262. "To 100 g. of oil in a 1000 to 1500-cc. Erlenmeyer flask add 60 cc. of an aqueous solution of potassium hydroxide (200 g. KOH dissolved in water and made up to 300 cc.) and 140 cc. of 95-per cent alcohol. Connect with a reflux condenser and heat on the water bath, shaking at first until the liquid becomes clear. Then heat for one hour with occasional shaking. Transfer while yet warm to a 2000-cc. separatory funnel to which some water has been added, wash out the Erlenmeyer with water using in all 600 cc. Cool, add 800 cc. of ether and shake vigorously one minute. In a few minutes the ether solution separates perfectly clear. Draw off the soap and filter the ether (to remove last traces of soap) into a large Erlenmeyer and distill off the ether, adding if necessary one or two pieces of pumice stone. Shake the soap solution three times with 400 cc. of ether, which add to the first ether extract. To the residue left after distilling the ether add 3 cc. of the above KOH solution, and 7 cc. of the 95-per cent alcohol, and heat under reflux condenser for 10 minutes on the water bath. Transfer to a small separatory funnel, using 20 to 30 cc. of water, and after cooling shake out with two portions of 100 cc. of ether; wash the ether three times with 10 cc. of water. After drawing off the last of the water, filter the ethereal solution so as to remove the last drops of water, distill off the ether, dry residue in water oven and weigh."

Refractive Index.—Use a properly standardized Abbé Refractometer at 25° C., or any other equally accurate instrument.

Iodine Number (*Hanus*).—Follow the Hanus method as described in Bulletin No. 107, revised 1908, Department of Agriculture, Bureau of Chemistry, page 136.

REPORT OF SUB-COMMITTEE F ON THE DEFINITION OF TERMS USED IN PAINT SPECIFICATIONS.

In its last report[1] this sub-committee submitted definitions of certain general terms frequently used in paint specifications. The sub-committee has added to that list proposed definitions of the following terms: covering power, hiding power, spreading power, fineness, hue, tone, drier, density, and gallon.

The sub-committee recommends that these definitions be adopted as standard by the Society. Very often these terms have been used in confusing and contradictory senses. It is hoped that by having standard definitions, paint specifications can be made clearer and less open to differences of opinion as to their meaning.

Respectfully submitted on behalf of the sub-committee,

G. W. THOMPSON,
Chairman.

[NOTE.—According to the regulations governing the adoption of proposed standard definitions, the definitions proposed in this report are printed in the Proceedings, subject to action at the next annual meeting.—ED.]

[1] *Proceedings*, Am. Soc. Test. Mats., Vol. XI, p. 223 (1911).

AMERICAN SOCIETY FOR TESTING MATERIALS

PHILADELPHIA, PA., U. S. A.

AFFILIATED WITH THE

INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

PROPOSED STANDARD DEFINITIONS OF TERMS USED IN PAINT SPECIFICATIONS.

Standard.—A term designating a quality or qualities specified.

Equal to.—The use of this term should be avoided if possible.

Pure.—Standard, without adulteration.

Commercially pure.—Is not defined and should not be used in specifications, as it involves the absence of "*standard.*"

Adulteration.—The partial substitution of one substance for another.

Adulterant.—A substance partially substituted for another.

Bulk.—The bulk of a pigment shall be considered as the total volume of the pigment and the voids, and varies inversely as the specific gravity of that volume.

Voids.—The space between the particles of a pigment, even though occupied by air or by a vehicle, whether liquid or dried.

Opacity.—The obstruction to the direct transmission of visible light afforded by any substance, comparison being made with sections of equal thickness. The opacity in the case of pigments should be considered as referable to their opacity in a vehicle under standard conditions.

Covering power.—The use of this expression should be avoided as being confusing.

Hiding power.—The power of a paint or paint material, as used, to obscure optically a surface painted with it.

Spreading power.—The relative capacity of a paint or paint material, as used, of being brushed out to a continuous uniform paint film expressed in terms of the area to which a unit volume, as used, is applied.

Fineness.—A term used to denote the extent of sub-division and expressive of the number of particles of pigment in a unit volume exclusive of voids.

Crystalline.—Having a definite structure referable to one of the systems of crystallography.

Amorphous.—The opposite of crystalline.

Paint.—A mixture of pigment with vehicle, intended to be spread in thin coats for decoration or protection, or both.

Pigment.—The fine solid particles used in the preparation of paint, and substantially insoluble in the vehicle.

Vehicle.—The liquid portion of a paint.

Volatile thinner.—All that liquid portion of a paint, except water, which is volatile in a current of steam at atmospheric pressure.

Non-volatile vehicle.—The liquid portion of a paint, excepting water, which is not a volatile thinner by the above definition.

Tinting strength.—The relative power of coloring a given quantity of paint or pigment selected as standard for comparison.

Color.—A generic term including the colors of the spectrum, white and black, and all tints, shades and hues which may be produced by their admixture.

Tint.—A color produced by the admixture of a commercial coloring material, excepting white, with a white pigment or paint, the white predominating.

Hue.—The predominating spectral color in a color mixture.

Tone.—The color which principally modifies a hue or a white or a black.

Drying.—The solidification of a liquid film, independent of change in temperature.

Drier.—A material containing metallic compounds added to paints for the purpose of accelerating drying.

Specific gravity.—The relative weight of a unit volume of a substance compared with the weight of the unit volume of water at defined temperatures.

Density.—This is a purely scientific term. Its use should be avoided in specifications.

Gallon.—The measured gallon is 231 cubic inches. Where a measured gallon is called for, the temperature at which it is to be measured should be specified. Where a weighed gallon is called for, the weight should be specified or obtained from the specific gravity of the material at a definite temperature.

Water.—Dissolved water or water not definitely or chemically combined.

Dry.—Containing no uncombined water.

REPORT OF SUB-COMMITTEE J ON THE TESTING OF WHITE PAINTS.

Sub-Committee J, on the Testing of White Paints, begs to submit the following report. The Proceedings of the Fourteenth Annual Meeting of the Society[1] contain the last published report of the sub-committee. The work planned in that report has been practically completed.

The pigments used were donated by the following manufacturers:

Acme White Lead & Color Co., Samuel H. French & Co., International Pulp Co., Mineral Point Zinc Co., National Lead Co., Neilsen, Klein & Krousse, New Jersey Zinc Co., The Patton Paint Co., Picher Lead Co., Westmoreland Chemical & Color Co., and C. K. Williams & Co.

The oil used in grinding the paints was donated by the American Linseed Co. and National Lead Co.

The drier and the oil used in thinning were donated by the National Lead Co.

The gasoline with which to clean the mills used in the grinding of the paints was donated by The Standard Oil Co.

The turpentine used in thinning the paints for first coats was donated by The Baltimore & Ohio Railroad Co.

The cans used were donated by The American Can Co.

The panels, which were strips of yellow poplar (Liriodendron tulipifera, L.) 8 by 1 by 36 in., were donated by The Pennsylvania Railroad Co.

The labor of applying the paint was donated by The Baltimore & Ohio Railroad Co.

The expense of constructing the frame and mounting the test pieces was shared equally by the Bureau of Chemistry of the Department of Agriculture, and the Bureau of Standards of the Department of Commerce and Labor.

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[1] Vol. XI, p. 225 (1911).

The specific gravities of the pigments used in calculating the formulas are as follows:

Samples Nos. 1 to 3.—Basic lead carbonate	6.6
Samples Nos. 4 to 5.—Zinc oxide	5.4
Sample No. 6.—Basic lead sulphate	6.3
Sample No. 7.—Leaded zinc oxide	5.61
Sample No. 8.—Silica	2.64
Sample No. 9.—Asbestine	2.78
Sample No. 10.—China clay	2.62
Sample No. 11.—Calcium carbonate	2.65
Sample No. 12.—Calcium sulphate	2.29
Sample No. 13.—Barytes	4.23

The specific gravities of the pigments actually used were determined in the laboratory of the National Lead Company by the following method:

Apparatus.—The apparatus used in this method consists of a burette, similar in shape to a thistle-tube, 38 in. high, having a capacity of 100 cc. with only 20 cc. graduated, each cubic centimeter having 50 divisions; the 20-cc. graduation has a length of 28¼ in., and the burette is 8 mm. in diameter in this length. Also, a 100-cc. graduated glass-stoppered flask with narrow neck, a short-stem 2-in. funnel, and a stiff piece of brass wire.

Finding the Capacity of Flask.—Fill the specific gravity burette with kerosene oil that has been filtered and find the capacity of the 100-cc. graduated glass-stoppered flask, letting the burette drain for 15 minutes before taking the reading. The precaution of letting the burette drain for 15 minutes before taking the reading should be followed in each determination. Note the temperature of the room and regulate the ventilation, having the temperature remain near this point while making all determinations.

Method.—Weigh out 100 g. of finely divided (crushed) sample of pigment, if the pigment is a fairly heavy one; if the pigment is a light one, weigh out 25 g. Place the weighed portion in the 100-cc. flask by running through the short-stem funnel, using the wire if necessary to aid in getting the pigment through the stem of the funnel. If desirable, the dry flask may be weighed before and after the addition of the pigment in the flask. Fill the specific gravity burette with kerosene oil; allow the oil to run into the flask containing the pigment until it is level with the 100-cc. mark on the flask, and put in the glass stopper. Place the neck of the flask between the palms of the hands and move one hand back and forth, giving the flask a rotating motion and wetting the pigment thoroughly with kerosene. To displace the last trace of air bubbles, tap the flask gently on a cloth-covered surface. Remove the glass stopper carefully, letting any kerosene that may have collected on the stopper run back into the flask. Make the volume in the flask up to the 100-cc. mark, adding more kerosene from the burette. This

operation should be repeated until the rotating motion and tapping do not change the volume of the kerosene in the flask, denoting that all of the air has been displaced. When the volume in the flask is constant, let the burette drain for the required time and then take the reading.

Letting A = Capacity of flask;
B = Reading of burette;
C = Volume of pigment in flask ($A - B = C$);
D = Weight in grams of the pigment used in determination; and
E = Specific gravity of the pigment;

the specific gravity of the pigment is $E = \frac{D}{A - B(=C)}$

Notes.—The most convenient temperature to work with will be room temperature, about 21° C., having the kerosene oil and apparatus in the room for some time before starting determinations.

To remove the kerosene from the flask after each determination, rinse the flask twice with ether and dry with air from blastlamp bellows.

The specific gravities obtained are as follows:

Sample No. 1.—Basic Lead Carbonate, designated by the manufacturer as Dutch Process White Lead..... 6.38
Sample No. 2.—Basic Lead Carbonate, designated by the manufacturer as Carter White Lead..... 6.72
Sample No. 3.—Basic Lead Carbonate, designated by the manufacturer as Mild Process White Lead..... 6.67
Sample No. 4.—Zinc Oxide, designated by the manufacturer as Florence Green Seal French Process Zinc Oxide..... 5.55
Sample No. 5.—Zinc Oxide, designated by the manufacturer as XX American Process Zinc Oxide..... 5.45
Sample No. 6.—Basic Lead Sulphate, designated by the manufacturer as Sublimed White Lead..... 6.33
Sample No. 7.—Leaded Zinc Oxide, designated by the manufacturer as Leaded Oxide of Zinc..... 5.68
Sample No. 8.—Siliceous Material, designated by the manufacturer as Silica..... 2.66
Sample No. 9.—Silicate, designated by the manufacturer as Asbestine. 2.77
Sample No. 10.—Clay, designated by the manufacturer as L.G.V. China Clay..... 2.60
Sample No. 11.—Calcium Carbonate, designated by the manufacturer as Extra Gilders Whiting, Bolted..... 2.68
Sample No. 12.—Calcium Sulphate, designated by the manufacturer as such..... 2.30
Sample No. 13.—Barium Sulphate, designated by the manufacturer as Cream Floated Lead Bloom (Water-Floated Barytes). 4.43

ANALYSES OF PIGMENTS.

The pigments were sampled by Messrs. Sabin and Rogers and samples were sent to a number of members of the committee who intended to make analyses. Up to the present time only two sets of analyses have been received, from the Bureau of Standards and the Bureau of Chemistry. As these analyses were made entirely independently, and differ in mode of expression, it is deemed best to report the results of each analyst independently of the other.

Following are the analyses reported from the Bureau of Standards:

SAMPLE NO. 1.—BASIC LEAD CARBONATE (DUTCH PROCESS WHITE LEAD).
(Lab. No. 1121, Test No. Ic-9).

	Per cent.
Carbonic anhydride (CO_2) { by evolution and absorption in soda lime: 11.69, 11.73 (Av. 11.7%). by combustion and absorption in soda lime: 11.8, 11.9, 11.8, 11.9	11.8
Total H_2O—by combustion and absorption in $CaCl_2$: 2.32, 2.31, 2.27.	2.30
Residue after ignition: 85.83, 85.81, 85.83, 85.86, 85.83	85.86
Lead oxide (PbO)—weighed as $PbSO_4$: 84.9, 85.0	85.0
Moisture—by drying at 95° C	0.26
Insoluble siliceous matter	0.03

Probable Composition.

Lead carbonate ($PbCO_3$)—calculated from CO_2 by evolution (11.7%)	71.0
Lead hydrate ($Pb(OH)_2$)—calculated from total H_2O corrected for moisture (2.04%)	27.3
Moisture	0.26
Insoluble siliceous matter	0.03

Color—white, slightly brown.

SAMPLE NO. 2.—BASIC LEAD CARBONATE (CARTER WHITE LEAD).
(Lab. No. 1122, Test No. Ic-9.)

	Per cent.
Carbonic anhydride (CO_2), { by evolution and absorption in soda lime: 11.60, 11.57 (Av. 11.6%). by combustion and absorption in soda lime: 11.7, 11.7, 11.7	11.7
Total H_2O—by combustion and absorption in $CaCl_2$: 2.35, 2.33, 2.312	2.34
Residue after ignition: 86.15, 86.15, 86.18	86.16

SAMPLE NO. 2.—*Continued.*

	Per cent.
Lead oxide (PbO)—weighed as $PbSO_4$: 85.8, 85.9	85.9
Moisture—by drying at 95° C	0.10
Insoluble siliceous matter	0.02

Probable Composition.

Lead Carbonate ($PbCO_3$)—calculated from CO_2 by evolution (11.6%)	70.3
Lead hydrate ($Pb(OH)_2$)—calculated from total H_2O corrected for moisture (2.24%)	30.0
Moisture	0.10
Insoluble siliceous matter	0.02

Color—practically white.

SAMPLE NO. 3—BASIC LEAD CARBONATE (MILD PROCESS WHITE LEAD).

(Lab. No. 1123, Test No. Ic-9.)

	Per cent.
Carbonic anhydride (CO_2), by evolution and absorption in soda lime: 11.57, 11.56 (Av. 11.6%). by combustion and absorption in soda lime: 11.7, 11.7, 11.7	11.7
Total H_2O—by combustion and absorption in $CaCl_2$: 2.17, 2.14, 2.17	2.16
Residue after ignition: 86.30, 86.28, 86.30	86.29

Lead oxide (PbO)—weighed as $PbSO_4$: 85.6, 85.7	85.7
Moisture—by drying at 95° C	0.08
Insoluble siliceous matter	0.05

Probable Composition.

Lead carbonate ($PbCO_3$)—calculated from CO_2 by evolution (11.57%)	70.2
Lead hydrate ($Pb(OH)_2$)—calculated from total H_2O corrected for moisture (2.08%)	27.9
Moisture	0.08
Insoluble siliceous matter	0.05

Color—white, with brownish tint.

SAMPLE NO. 4.—ZINC OXIDE (FLORENCE GREEN SEAL FRENCH PROCESS ZINC OXIDE).

(Lab. No. 1124, Test No. Ic-9.)

	Per cent.
Zinc oxide (ZnO)—titrated with $K_4Fe(CN)_6$	99.36
Lead oxide (PbO)—determined as sulphate	0.25
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	0.07
Sulphuric anhydride (SO_3)	0.16
Moisture—by drying at 105° C	0.10

Color—white.

SAMPLE NO. 5.—ZINC OXIDE (XX AMERICAN PROCESS ZINC OXIDE).

(Lab. No. 1125, Test No. Ic-9.)

	Per cent.
Zinc oxide (ZnO)—titrated with $K_4Fe(CN)_6$	98.88
Lead oxide (PbO)—determined as sulphate	0.21
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	0.22
Sulphuric anhydride (SO_3)	0.38
Moisture—by drying at 105° C	0.24
Color—white, with a yellowish brown tint.	

SAMPLE NO. 6.—BASIC LEAD SULPHATE (SUBLIMED WHITE LEAD).

(Lab. No. 1126, Test No. Ic-9.)

	Per cent.
Lead oxide (PbO)—determined as sulphate	72.20
Zinc oxide (ZnO)—titrated with $K_4Fe(CN)_6$	6.16
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	0.08
Sulphuric anhydride (SO_3)	21.19
Moisture—by drying at 105° C	0.10
Loss by ignition after drying	0.19

Probable Composition.

Lead sulphate ($PbSO_4$)	80.22
Lead oxide (PbO)	13.17
Zinc oxide (ZnO)	6.16
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	0.08
Moisture, organic matter, etc	0.29
Color—white, with a yellowish brown tint.	

SAMPLE NO. 7.—LEADED ZINC OXIDE (LEADED OXIDE OF ZINC).

(Lab. No. 1127, Test No. Ic-9.)

	Per cent.
Lead oxide (PbO)—determined as sulphate	11.37
Zinc oxide (ZnO)—titrated with $K_4Fe(CN)_6$	84.90
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	0.10
Sulphuric anhydride (SO_3)	3.54
Moisture—by drying at 105° C	0.18

Probable Composition.

Lead sulphate ($PbSO_4$)	13.40
Lead oxide (PbO)	1.51
Zinc oxide (ZnO)	84.90
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	0.10
Moisture	0.18
Color—white, with a shade of yellowish brown.	

SAMPLE NO. 8.—SILICEOUS MATERIAL (SILICA).

(Lab. No. 1128, Test No. Ic-9.)

	Per cent.
Soluble in HCl (1:5)	16.49
Insoluble in HCl (1:5)	80.17
Loss on ignition	4.85

Soluble Portion.

Lime (CaO)—oxalate titrated with $KMnO_4$	3.75
Magnesia (MgO)—weighed as pyrophosphate	6.63
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	0.57
Silicia (SiO_2)	1.78
Carbonic anhydride (CO_2)—by evolution and absorption in soda lime	3.59
Moisture—by drying at 105° C	0.17

Insoluble Portion.—The insoluble portion was fused with Na_2CO_3, and the following analysis obtained:

Lime (CaO)—oxalate titrated with $KMnO_4$	1.76
Magnesia (MgO)—as pyrophosphate	8.81
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	0.47
Silica (SiO_2)	68.12

Color—white, tinted with gray.

SAMPLE NO. 9.—SILICATE (ASBESTINE).

(Lab. No. 1129, Test No. Ic-9.)

	Per cent.
Soluble in HCl (1:5)	7.67
Insoluble in HCl (1:5)	89.57
Loss on ignition	2.25

Soluble Portion.

Lime (CaO)—oxalate titrated with $KMnO_4$	0.39
Magnesia (MgO)—as pyrophosphate	5.26
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	0.14
Silica (SiO_2)	1.63
Moisture—by drying at 105° C	0.25

Insoluble Portion.—The insoluble portion was fused with Na_2CO_3, and the following analysis obtained:

Lime (CaO)—oxalate titrated with $KMnO_4$	5.19
Magnesia (MgO)—as pyrophosphate	23.35
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	0.35
Silica (SiO_2)	58.95

Color—white, with a very light tint of brown.

SAMPLE NO. 10.—CLAY (L. G. V. CHINA CLAY).

(Lab. No. 1130, Test No. Ic-9.)

	Per cent.
Loss on ignition	12.65
Oxide of aluminum (Al_2O_3)	38.75
Magnesia (MgO)—as pyrophosphate	0.25
Silica (SiO_2)	46.59
Color—white, with a brownish tinge.	

SAMPLE NO. 11.—CALCIUM CARBONATE (EXTRA GILDERS WHITING, BOLTED).

(Lab. No. 1131, Test No. Ic-9.)

	Per cent.
Lime (CaO)—weighed as CaO from the oxalate	54.82
Magnesia (MgO)—as pyrophosphate	0.29
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	0.25
Carbonic anhydride (CO_2)—by evolution and absorption in soda lime	42.98
Insoluble	1.15
Moisture—by drying at 105° C	0.13

Probable Composition.

Calcium carbonate ($CaCO_3$)	97.86
Magnesium carbonate ($MgCO_3$)	0.60
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	0.25
Clay	1.15
Moisture	0.13
Color—white, slightly tinted yellowish brown.	

SAMPLE NO. 12.—CALCIUM SULPHATE.

(Lab. No. 1132, Test No. Ic-9.)

	Per cent.
Lime (CaO)—weighed as CaO from the oxalate	32.84
Magnesia (MgO)—as pyrophosphate	0.10
Sulphuric anhydride (SO_3)	45.55
Carbonic anhydride (CO_2)—by evolution and absorption in soda lime	0.70
Insoluble	0.40
Loss at dull red heat (moisture, combined water, etc.)	20.54

Probable Composition.

Calcium sulphate ($CaSO_4$)	77.2
Magnesium sulphate ($MgSO_4$)	0.3
Calcium carbonate ($CaCO_3$)	1.6
Clay	0.4
Water, etc.	20.5
Color—white, with a gray tint.	

SAMPLE NO. 13.—BARIUM SULPHATE (CREAM FLOATED LEAD BLOOM—WATER-FLOATED BARYTES).

(Lab. No. 1132, Test No. Ic-9.)

The material was boiled with HCl (1:5).

Soluble Portion.	Per cent.
Silica (SiO_2)	0.25
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	1.05
Magnesia (MgO)	0.11
Sulphuric anhydride (SO_3)	0.34
Loss on ignition	0.30

Insoluble Portion.—98.30 per cent, after fusion with Na_2CO_3, showed no other ingredients present except Barium Sulphate ($BaSO_4$).

Color—white.

It was the original intention of the Bureau of Standards to make a very complete analysis of each of the pigments included in these tests, and also to state in detail the methods of analysis employed. This, however, was found impossible. As the methods used were not novel and in most cases the method of determination is indicated, a further discussion is not considered necessary.

Following are the results of analyses made at the Bureau of Chemistry:

SAMPLE NO. 1.—BASIC LEAD CARBONATE (DUTCH PROCESS WHITE LEAD).

(Contract No. 11520.)

		Per cent.
Specific gravity at $\frac{15°.5}{15°.5}$ C. (pyknometer)	6.46	
Moisture (H_2O)—vacuum desiccator method		0.63
2 hr. in air bath at 105° C	0.69	
76 " " " " " 105° C	0.87	
17 hr. in water-jacketed oven at 99° C	0.71	
CaC_2 method	0.61	
Total loss on ignition		14.4
Total lead as PbO—$PbSO_4$ method		85.0
$PbCrO_4$ gravimetric method (Fresenius)	85.2	
$PbCrO_4$ gravimetric method (McDonnell)	85.1	
Ignition and correction for non-volatile other than PbO	85.2	

SAMPLE NO. 1.—*Continued.*

	Per cent.
Carbonic anhydride (CO_2)—evolution with acid and weighing as $BaCO_3$	11.7 (=71.0% $PbCO_3$).
Evolution with acid and weighing in KOH bulb	11.6
Direct ignition, weighing in soda lime	11.7
Combined water (H_2O)—direct ignition and weighing in $CaCl_2$ tube corrected for moisture	2.02 (=27.1% $Pb(OH)_2$).
Calculated from total loss on ignition, moisture and CO_2	2.07
Acetates as CH_3COOH—Thompson's method	0.12
Insoluble siliceous matter (SiO_2, etc.)	0.03
Lead oxide (PbO)—insoluble in CH_3COOH and soluble in CH_3COONH_4	0.25 (=0.34% $PbSO_4$).
Lead oxide (PbO)—insoluble in CH_3COOH and CH_3COONH_4, but soluble in HNO_3	0.00 (=0.00% $PbSO_3$).
Sulphuric anhydride (SO_3)	0.08 (=0.31% $PbSO_4$).
Sulphurous anhydride (SO_2)	0.00 (=0.00% $PbSO_3$).
Bismuth as Bi_2O_3—32-g. sample taken; weighed as BiOCl	0.02
Iron as Fe_2O_3—10 to 32-g. sample taken; final weighing as Fe_2O_3	0.01
Lime (CaO)—10 to 32-g. sample taken; final weighing as CaO	0.05
Magnesia (MgO)—10 to 32-g. sample taken; final weighing as MgO (ammonium carbonate method)	0.04
Alkalies as Na_2O—10-g. sample taken; final weighing as Na_2SO_4	0.19

SAMPLE NO. 2.—BASIC LEAD CARBONATE (CARTER WHITE LEAD).
(Contract No. 11521.)

	Per cent.
Specific gravity at $\frac{15°.5}{15°.5}$ C. (pyknometer),	6.85
Moisture (H_2O)—vacuum desiccator method	0.09
2 hr. in air bath at 105° C	0.12
CaC_2 method	0.09
Total loss on ignition	13.8
Total lead as PbO—$PbSO_4$ method	86.2
$PbCrO_4$ gravimetric method (Fresenius)	86.4
$PbCrO_4$ gravimetric method (McDonnell)	86.2
Ignition and correction for nonvolatile other than PbO	86.1

SAMPLE NO. 2.—*Continued.*

	Per cent.	
Carbonic anhydride (CO_2)—evolution with acid and weighing as $BaCO_3$	11.6	(=70.4% $PbCO_3$).
Evolution with acid and weighing in KOH bulb	11.6	
Direct ignition, weighing in soda lime	11.7	
Combined water (H_2O)—direct ignition and weighing in $CaCl_2$ tube corrected for moisture	2.20	(=29.5% $Pb(OH)_2$)
Calculated from total loss on ignition, moisture and CO_2	2.10	
Acetates as CH_3COOH—Thompson's method	0.15	
Insoluble siliceous matter (SiO_2, etc.)	0.01	
Lead oxide (PbO)—insoluble in CH_3COOH and soluble in CH_3COONH_4	0.23	(=0.31% $PbSO_4$).
Lead oxide (PbO)—insolubie in CH_3COOH and CH_3COONH_4, but soluble in HNO_3	0.00	(=0.00% $PbSO_4$).
Sulphuric anhydride (SO_3)	0.08	(=0.31% $PbSO_4$).
Sulphurous anhydride (SO_2)	0.02	(=0.09% $PbSO_4$).
Bismuth as Bi_2O_3—32-g. sample taken; weighed as BiOCl	0.03	
Iron as Fe_2O_3—10 to 32-g. sample taken; final weighing as Fe_2O_3	0.01	
Lime (CaO)—10 to 32-g. sample taken; final weighing as CaO	0.01	
Magnesia (MgO)—10 to 32-g. sample taken; final weighing as MgO (ammonium carbonate method)	0.01	
Alkalies as Na_2O—10-g. sample taken; final weighing as Na_2SO_4	0.05	

SAMPLE NO. 3.—BASIC LEAD CARBONATE (MILD PROCESS WHITE LEAD.)
(Contract No. 11522.)

	Per cent.	
Specific gravity at $\frac{15°.5}{15°.5}$ C. (pyknometer),	6.85	
Moisture (H_2O)—vacuum desiccator method	0.04	
2 hr. in air bath at 105° C.	0.19	
CaC_2 method	0.19	
Total loss on ignition	13.8	
Total lead as PbO—$PbSO_4$ method	86.1	
$PbCrO_4$ gravimetric method (Fresenius)	86.4	
$PbCrO_4$ gravimetric method (McDonnell)	86.5	

SAMPLE NO. 3.—*Continued.*

	Per cent.	
Ignition and correction for non-volatile other than PbO	86.2	
Carbonic anhydride (CO_2)—evolution with acid and weighing as $BaCO_3$	11.6	(=70.4% $PbCO_3$).
Evolution with acid and weighing in KOH bulb	11.6	
Direct ignition, weighing in soda lime	11.7	
Combined water (H_2O)—direct ignition and weighing in $CaCl_2$ tube corrected for moisture	2.17	(=29.1% $Pb(OH)_2$)
Calculated from total loss on ignition, moisture and CO_2	2.09	
Acetates as CH_3COOH—Thompson's method	0.00	
Insoluble siliceous matter (SiO_2, etc.)	0.06	
Lead oxide (PbO)—insoluble in CH_3COOH and soluble in CH_3COONH_4	0.67	(=0.91% $PbSO_4$).
Lead oxide (PbO)—insoluble in CH_3COOH and CH_3COONH_4, but soluble in HNO_3	0.11	(=0.14% $PbSO_3$).
Sulphuric anhydride (SO_3)	0.23	(=0.87% $PbSO_4$).
Sulphurous anhydride (SO_2)	0.06	(=0.27% $PbSO_3$).
Bismuth as Bi_2O_3—32-g. sample taken; final weighing as BiOCl	trace	
Iron as Fe_2O_3—10 to 32-g. sample taken; final weighing as Fe_2O_3	0.02	
Lime (CaO)—10 to 32-g. sample taken; final weighing as CaO	0.01	
Magnesia (MgO)—10 to 32-g. sample taken; final weighing as MgO (ammonium carbonate method)	0.01	
Alkalies as Na_2O—10-g. sample taken; final weighing as Na_2SO_4	0.03	

SAMPLE NO. 4.—ZINC OXIDE (FLORENCE GREEN SEAL FRENCH PROCESS ZINC OXIDE).

(Contract No. 11523.)

	Per cent.	
Specific gravity at $\frac{15°.5}{15°.5}$ C. (pyknometer)	5.68	
Color—white.		
Moisture (H_2O)—vacuum desiccator method	0.09	
2 hr. in air bath at 105° C.	0.08	
CaC_2 method	0.11	
Total loss on ignition	0.20	
Insoluble siliceous matter (SiO_2, etc.)	0.01	

SAMPLE NO. 4.—*Continued.*

	Per cent.
Total zinc as ZnO	99.3
Total lead as PbO	0.26
Arsenic—calculated as As_2O_3	trace
Antimony	not detected
Iron as Fe_2O_3	0.04
Alumina (Al_2O_3)	0.05
Manganese as MnO	not detected
Cadmium as CdO	0.08
Calcium	not detected
Magnesium	not detected
Carbonic anhydride (CO_2)	0.08
Chlorine (Cl)	0.05
Total sulphuric anhydride (SO_3)	0.19
Sulphurous anhydride (SO_2)	not detected
Water-soluble zinc as ZnO	0.06 (=0.13% $ZnSO_4$).
Excess SO_3—calculated to $PbSO_4$	0.45 (=0.33% PbO).
Bismuth, copper, silver, and tin	not detected
Alkalies	not tested for

SAMPLE NO. 5.—ZINC OXIDE (XX AMERICAN PROCESS ZINC OXIDE).
(Contract No. 11524.)

	Per cent.	
Specific gravity at $\frac{15°.5}{15°.5}$ C. (pyknometer)	5.60	
Color—yellowish white.		
Moisture (H_2O)—vacuum desiccator method		0.16
2 hr. in air bath at 105° C.	0.16	
CaC_2 method	0.16	
Total loss on ignition		0.86
Insoluble siliceous matter (SiO_2, etc.)		0.02
Total zinc as ZnO		98.4
Total lead as PbO		0.37
Arsenic—calculated as As_2O_3		0.16
Antimony		trace.
Iron as Fe_2O_3		0.06
Alumina (Al_2O_3)		0.07
Manganese as MnO		0.03
Cadmium as CdO		0.07
Calcium		not detected
Magnesium		not detected
Carbonic anhydride (CO_2)		0.05
Chlorine (Cl)		0.09
Total sulphuric anhydride (SO_3)		0.42
Sulphurous anhydride (SO_2)		trace

SAMPLE NO 5.—*Continued.*

	Per cent.
Water-soluble zinc as ZnO	0.47 (=0.94% $ZnSO_4$).
Excess SO_3—calculated as $PbSO_4$	0.00
Bismuth, copper, silver, and tin	not detected
Alkalies	not tested for

SAMPLE NO. 6.—BASIC LEAD SULPHATE (SUBLIMED WHITE LEAD).
(Contract No. 11525.)

	Per cent.
Specific gravity at $\frac{15°.5}{15°.5}$ C. (pyknometer)	6.43
Moisture (H_2O)—vacuum desiccator method	0.07
CaC_2 method	0.06
Bismuth—1-g. sample taken	trace
Total lead as PbO	72.4
Total zinc as ZnO	5.7
Total sulphuric anhydride (SO_3)	22.1
Soluble sulphuric anhydride (SO_3)	0.12

Qualitative tests using small portions failed to detect other ingredients.

Probable Composition (calculated).

Lead sulphate ($PbSO_4$)	83.0
Lead oxide (PbO)	11.1
Zinc sulphate ($ZnSO_4$)	0.3
Zinc oxide (ZnO)	5.6

SAMPLE NO. 7.—LEADED ZINC OXIDE (LEADED OXIDE OF ZINC).
(Contract No. 11526.)

	Per cent.
Specific gravity at $\frac{15°.5}{15°.5}$ C. (pyknometer)	5.79
Moisture (H_2O)—vacuum desiccator method	0.08
CaC_2 method	0.12
Total lead as PbO	11.5
Total zinc as ZnO	85.1
Total sulphuric anhydride (SO_3)	4.0
Soluble sulphuric anhydride (SO_3)	0:23

Qualitative tests using small portions failed to detect other ingredients.

Probable Composition (calculated).

Lead sulphate ($PbSO_4$)	14.0
Lead oxide (PbO)	1.1
Zinc sulphate ($ZnSO_4$)	0.5
Zinc oxide (ZnO)	84.4

SAMPLE NO. 8.—SILICEOUS MATERIAL (SILICA).
(Contract No. 11527.)

	Per cent.
Specific gravity at $\frac{15°.5}{15°.5}$ C. (pyknometer)	2.69
Moisture (H_2O)—vacuum desiccator method	0.25
CaC_2 method	0.22
Total loss on ignition	7.22
Silica (SiO_2)	69.9
Iron oxide and alumina ($Fe_2O_3+Al_2O_3$)—uncorrected	0.92
Lime (CaO)	5.74
Magnesia (MgO)	16.0
Manganese—1 g. of material taken	trace

Qualitative tests using small portions (about 1 g.) failed to detect other ingredients.

SAMPLE NO. 9.—SILICATE (ASBESTINE)
(Contract No. 11528.)

	Per cent.
Specific gravity at $\frac{15°.5}{15°.5}$ C. (pyknometer)	2.80
Moisture (H_2O)—vacuum desiccator method	0.71
2 hr. in air bath at 105° C	0.72
CaC_2 method	0.61
Total loss on ignition	5.09
Silica (SiO_2)	60.1
Alumina (Al_2O_3)—uncorrected	0.27
Iron as Fe_2O_3	0.22
Manganese as MnO	0.53
Lime (CaO)	5.40
Magnesia (MgO)	28.9

SAMPLE NO. 10.—CLAY (L. G. V. CHINA CLAY).
(Contract No. 11529.)

	Per cent.
Specific gravity at $\frac{15°.5}{15°.5}$ C. (pyknometer)	2.60
Moisture (H_2O)—vacuum desiccator method	0.58
CaC_2 method	0.53
Total loss on ignition	12.9
Silica (SiO_2)	46.5
Iron oxide and alumina ($Fe_2O_3+Al_2O_3$)—uncorrected	40.8
Titanium phosphorus, and unusual elements	not tested for

SAMPLE NO. 11.—CALCIUM CARBONATE (EXTRA GILDERS WHITING, BOLTED).
(Contract No. 11530.)

	Per cent.
Specific gravity at $\frac{15°.5}{15°.5}$ C. (pyknometer)	2.69
Moisture (H_2O)—vacuum desiccator method	0.14
2 hr. in air bath at 105° C.	0.15
CaC_2 method	0.17
Total loss on ignition	43.6
Carbonic anhydride (CO_2)—evolution with acid and weighing as $BaCO_3$	43.5
Evolution with acid and weighing in KOH bulb	43.5
Sulphuric anhydride (SO_3)	0.26
Total insoluble siliceous matter	1.02
Silica (SiO_2)	0.59
Alumina (Al_2O_3)	0.16
Iron as Fe_2O_3	0.11
Lime (CaO)	54.7
Magnesia (MgO)	0.31

SAMPLE NO. 12.—CALCIUM SULPHATE.
(Contract No. 11531.)

	Per cent.
Specific gravity at $\frac{15°.5}{15°.5}$ C. (pyknometer)	2.33
Moisture (H_2O)—vacuum desiccator method	0.13
Total loss in air bath at 105° C. for 27 hr	19.7
Total loss in air bath at 200°–220° C. constant weight, about 10 hr	20.2
CaC_2 method:—Some combined H_2O given off below 100° C. (The vacuum desiccator method is the only one which gives results at all reliable.)	
Total loss by heating to low redness	20.4
Insoluble siliceous matter	0.40
Iron oxide and alumina ($Fe_2O_3+Al_2O_3$)	0.00
Lime (CaO)	32.7
Magnesia (MgO)	0.13
Sulphuric anhydride (SO_3)	45.6
Carbonic anhydride (CO_2)	0.67

SAMPLE NO. 13.—BARIUM SULPHATE (CREAM FLOATED LEAD BLOOM—WATER-FLOATED BARYTES).
(Contract No. 11532.)

	Per cent.
Specific gravity at $\frac{15°.5}{15°.5}$ C. (pyknometer)	4.47
Moisture (H_2O)—vacuum desiccator method	0.05
2 hr. in air bath at 105° C	0.06
CaC_2 method	0.07
Total loss on ignition	0.27
Silica (SiO_2)	0.26
Total sulphuric anhydride (SO_3)	34.3
Alumina (Al_2O_3, etc.)—uncorrected	1.00
Iron oxide (Fe_2O_3)	0.04
Baryta (BaO)	64.6
Lime (CaO)	0.02
Magnesia (MgO)	0.13

The Bureau of Chemistry intended to make exhaustive analyses of all the samples, but it was found that the necessary time could not be given for this work on all of them. The analyses of the three samples of white lead, however, are complete, and the samples were used to test the accuracy of some of the methods of determination. It is clear from the figures found that moisture determinations in such materials are exceedingly difficult, and the calculations of the amounts of lead carbonate and lead hydrate are therefore subject to very great errors. When we consider that moisture determinations by methods which are generally considered standard may vary by nearly 0.2 per cent, which would correspond to over 2.6 per cent of lead hydrate, and that the CO_2 determinations frequently vary as much as 0.2 per cent, even with the most skillful analyst, it would appear that any attempt to calculate accurately the amount of carbonate and hydrate in a sample of white lead is nearly impossible for routine work.

The specific gravity determinations were all made with a pyknometer, which method is, in the opinion of the sub-committee, unsatisfactory for determining the specific gravity of pigments. A method similar to that used with cements should be employed, but this would have necessitated the use of larger quantities of the pigment than would have been justified from the quantity of the samples submitted.

ANALYSES OF OILS, TURPENTINE AND DRIER.

A chemical analysis of the oil used in grinding the paints, made at the Bureau of Standards, follows:

RAW LINSEED OIL.

(Lab. No. 1404, Test No. Ic-9.)

Specific gravity at $\frac{15°.5}{15°.5}$ C	0.9326
Ash, siliceous, per cent	0.12
Acid number	1.4
Iodine number	190.2
Saponification number	190.4

A chemical analysis of the oil used in thinning the paints for the first coats, made at the Bureau of Chemistry, follows:

RAW LINSEED OIL.

(Contract No. 15553.)

Specific gravity at $\frac{15°.5}{15°.5}$ C	0.9356
Color	normal
Odor	normal
Taste	normal
Turbidity	considerable
Foots	considerable
Loss (½ hr. at 105° C.), per cent	0.27
Saponification number	191.4
Acid number	1.9
Iodine number (Hanus) of oil	188.4
Iodine number (Hanus) of insoluble fatty acids	196.6
Unsaponifiable, per cent	1.22
Ash, per cent	0.19
Refractive index at 25° C	1.4803

A chemical analysis of the turpentine used in thinning the first coats, made in the Bureau of Chemistry, follows:

TURPENTINE.

(L. & P. No. 24552, Contract No. 15552.)

Specific gravity at 20° C	0.8644
Color:—more than 200 mm. required to equal in color Lovibond yellow glass No. 1.	
Odor	gum spirits
Refractive index at 20° C	1.4680

TURPENTINE.—*Continued.*

Distillation at 760 mm. pressure:	
Initial boiling point	158° C.
Below 160° C., per cent	7.9
Below 165° C., "	92.4
Below 170° C., "	96.6
Residue, "	3.4
Polymerization residue, "	0.4
Consistency of residue	viscous
Boil-down test (100° C.), per cent	0.5
Drop on white paper	no residue

A sample of the drier used in making the paints was analyzed at the Bureau of Chemistry and gave the following results:

DRIER FOR WHITE PIGMENT TESTS.

(From Dr. Allen Rogers, Am. Soc. Test. Mats.; Contract No. 15578.)

Appearance	dark brown, turbid, very viscous
Odor	heated linseed oil
Specific gravity at $\frac{15°.5}{15°.5}$ C	0.985
Water	small amount
Volatile oil	none
Total lead (Pb), per cent	2.51
Total manganese (Mn), per cent	1.09
Lime	very small amount
Total ash, per cent	4.54
Reaction of ash	faintly alkaline
Acid number	28.0
Rosin	not detected

When mixed with 8 parts raw linseed oil, the material shows a turbidity and a deposit on standing.

The mixture dries free from tackiness in 2 hrs.

The mixture dries hard in more than 8 and less than 24 hrs.

Nature of film after 24 hrs.: hard, clear and elastic.

DESCRIPTION OF TESTS.

The paints were prepared by Prof. Allen Rogers of Pratt Institute, Brooklyn, according to the plan outlined in the last report.[1] In order to obtain a standard consistency for the paints used in the test, Professor Rogers, The Patton Paint Co., and the Sherwin-Williams Co., prepared independently a paint which they considered of the proper consistency. Professor

[1] *Proceedings*, Am. Soc. Test. Mats., Vol. XI, p. 225 (1911).

TABLE I.—COMPOSITION OF SINGLE-PIGMENT PAINTS

Paint No.	No. 1—Basic Lead Carbonate, lb.	No. 2—Basic Lead Carbonate, lb.	No. 3—Basic Lead Carbonate, lb.	No. 4—Zinc Oxide, lb.	No. 5—Zinc Oxide, lb.	No. 6—Basic Lead Sulphate, lb.	No. 7—Leaded Zinc Oxide, lb.	No. 8—Siliceous Material, lb.	No. 9—Silicate, lb.	No. 10—Clay, lb.	No. 11—Calcium Carbonate, lb.	No. 12—Calcium Sulphate, lb.	No. 13—Barium Sulphate, lb.	Ground in — Oz. of Oil.
101	41.25	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	96
102	.....	41.25	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	96
103	.....	.....	41.25	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	144
104	.....	.....	.....	34.75	.....	.....	.....	.....	.....	.....	.....	.....	.....	224
105	.....	.....	.....	.....	34.75	.....	.....	.....	.....	.....	.....	.....	.....	240
106	.....	.....	.....	.....	.....	39.50	.....	.....	.....	.....	.....	.....	.....	112
107	.....	.....	.....	.....	.....	.....	35	.....	.....	.....	.....	.....	.....	128

TABLE II.—COMPOSITION OF TWO-PIGMENT PAINTS

201	33.00	.....	.....	6.75	.....	.....	.....	.....	.....	.....	.....	.....	.....	128
202	33.00	.....	.....	.....	.....	7.75	.....	.....	.....	.....	.....	.....	.....	128
203	33.00	.....	.....	.....	.....	.....	.....	3.25	.....	.....	.....	.....	.....	96
204	33.00	.....	.....	.....	.....	.....	.....	.....	3.50	.....	.....	.....	.....	96
205	33.00	.....	.....	.....	.....	.....	.....	.....	.....	3.25	.....	.....	.....	96
206	33.00	.....	.....	.....	.....	.....	.....	.....	.....	.....	3.25	.....	.....	96
207	33.00	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	2.75	.....	96
208	33.00	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	5.25	96
209	20.50	.....	.....	17.00	.....	.....	.....	.....	.....	.....	.....	.....	.....	196
210	20.50	.....	.....	.....	.....	19.75	.....	.....	.....	.....	.....	.....	.....	104
211	20.50	.....	.....	.....	.....	.....	.....	8.25	.....	.....	.....	.....	.....	96
212	20.50	.....	.....	.....	.....	.....	.....	.....	8.75	.....	.....	.....	.....	100
213	20.50	.....	.....	.....	.....	.....	.....	.....	.....	8.25	.....	.....	.....	112
214	20.50	.....	.....	.....	.....	.....	.....	.....	.....	.....	8.25	.....	.....	96
215	20.50	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	7.00	.....	96
216	20.50	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	13.00	96
217	24.50	.....	.....	13.50	.....	.....	.....	.....	.....	.....	.....	.....	.....	128
218	24.50	.....	.....	.....	13.50	.....	.....	.....	.....	.....	.....	.....	.....	128
219	24.50	.....	.....	.....	.....	15.75	.....	.....	.....	.....	.....	.....	.....	96
221	.....	.....	.....	.....	17.00	19.75	.....	.....	.....	.....	.....	.....	.....	160
222	.....	.....	.....	.....	17.00	.....	.....	8.25	.....	.....	.....	.....	.....	160
223	.....	.....	.....	.....	17.00	.....	.....	.....	8.75	.....	.....	.....	.....	144
224	.....	.....	.....	.....	17.00	.....	.....	.....	.....	8.25	.....	.....	.....	192
225	.....	.....	.....	.....	17.00	.....	.....	.....	.....	.....	8.25	.....	.....	160
226	.....	.....	.....	.....	17.00	.....	.....	.....	.....	.....	.....	7.00	.....	136
227	.....	.....	.....	.....	17.00	.....	.....	.....	.....	.....	.....	.....	13.00	144
228	.....	.....	.....	.....	.....	19.75	.....	8.25	.....	.....	.....	.....	.....	88
229	.....	.....	.....	.....	.....	19.75	.....	.....	8.75	.....	.....	.....	.....	112
230	.....	.....	.....	.....	.....	19.75	.....	.....	.....	8.25	.....	.....	.....	152
231	.....	.....	.....	.....	.....	19.75	.....	.....	.....	.....	8.25	.....	.....	96
232	.....	.....	.....	.....	.....	19.75	.....	.....	.....	.....	.....	7.00	.....	96
233	.....	.....	.....	.....	.....	19.75	.....	.....	.....	.....	.....	.....	13.00	96
234	16.50	.....	.....	20.25	.....	.....	.....	.....	.....	.....	.....	.....	.....	136
235	16.50	.....	.....	.....	20.25	.....	.....	.....	.....	.....	.....	.....	.....	152

ABLE I.—COMPOSITION OF SINGLE-PIGMENT PAINTS.

No. 8—Siliceous Material, lb.	No. 9—Silicate, lb.	No. 10—Clay, lb.	No. 11—Calcium Carbonate, lb.	No. 12—Calcium Sulphate, lb.	No. 13—Barium Sulphate, lb.	Ground in — Oz. of Oil.	Thinned with — Oz. of Oil.	Total Bulk of Paint, oz.
.....	.....	.....	.....	.....	.....	96	176	368
.....	.....	.....	.....	.....	.....	96	160	352
.....	.....	.....	.....	.....	.....	144	216	456
.....	.....	.....	.....	.....	.....	224	486	808
.....	.....	.....	.....	.....	.....	240	384	720
.....	.....	.....	.....	.....		112	264	472
.....	.....	.....	.....	.....	.....	128	268	492

ABLE II.—COMPOSITION OF TWO-PIGMENT PAINTS.

.....	.....	.....	.....	.....	.....	128	216	440
.....	.....	.....	.....	.....	.....	128	176	400
3.25	.....	.....	.....	.....	.....	96	182	374
.....	3.50	.....	.....	.....	.....	96	308	500
.....	.....	3.25	.....	.....	.....	96	192	384
.....	.....	.....	3.25	.....	.....	96	168	360
.....	.....	.....	.....	2.75	.....	96	174	366
.....	.....	.....	.....	.....	5.25	96	136	328
.....	.....	.....	.....	.....	.....	196	268	560
.....	.....	.....	.....	.....	.....	104	156	356
8.25	.....	.....	.....	.....	.....	96	128	320
.....	8.75	.....	.....	.....	.....	100	144	340
.....	.....	8.25	.....	.....	.....	112	168	376
.....	.....	.....	8.25	.....	.....	96	128	320
.....	.....	.....	.....	7.00	.....	96	96	288
.....	.....	.....	.....	.....	13.00	96	76	268
.....	.....	.....	.....	.....	.....	128	244	468
.....	.....	.....	.....	.....	.....	128	232	456
.....	.....	.....	.....	.....	.....	96	168	360
.....	.....	.....	.....	.....	.....	160	304	560
8.25	.....	.....	.....	.....	.....	160	240	496
.....	8.75	.....	.....	.....	.....	144	288	528
.....	.....	8.25	.....	.....	.....	192	282	570
.....	.....	.....	8.25	.....	.....	160	226	482
.....	.....	.....	.....	7.00	.....	136	234	466
.....	.....	.....	.....	.....	13.00	144	224	464
8.25	.....	.....	.....	.....	.....	88	170	354
.....	8.75	.....	.....	.....	.....	112	224	432
.....	.....	8.25	.....	.....	.....	152	208	456
.....	.....	.....	8.25	.....	.....	96	136	328
.....	.....	.....	.....	7.00	.....	96	130	322
.....	.....	.....	.....	.....	13.00	96	128	320
.....	.....	.....	.....	.....	.....	136	260	492
.....	.....	.....	.....	.....	.....	152	220	468

PLATE IX.
PROC. AM. SOC. TEST. MATS.
VOL. XIII.
REPORT OF SUB-COMMITTEE J
OF COMMITTEE D-1.

Total Bulk of Paint, oz.	Volume of Oil, oz. per gal.	Volume of Pigment, oz. per gal.	Weight of Pigment per Gal., lb.	Weight of Paint per Gal., lb.	Drier, oz. per gal.	Paint No.
368	94	34	14.6	20.3	4.75	101
352	93	35	15.0	20.6	4.65	102
456	101	27	10.8	16.9	5.05	103
808	112	16	5.6	12.4	5.60	104
720	111	17	7.2	13.9	5.50	105
472	102	26	10.6	16.8	5.10	106
492	103	25	9.0	15.2	5.15	107
440	100	28	11.5	17.5	5.00	201
400	97	31	13.1	18.9	4.85	202
374	95	33	12.4	18.1	4.75	203
500	103	25	9.4	15.6	5.15	204
384	96	32	12.1	18.0	4.80	205
360	93	35	13.2	18.8	4.65	206
366	94	34	12.6	18.3	4.70	207
328	90	38	15.0	20.4	4.50	208
560	106	22	8.4	14.8	5.30	209
356	93	35	14.7	20.3	4.65	210
320	89	39	11.6	18.4	4.45	211
340	92	36	10.9	16.9	4.60	212
376	95	33	9.9	15.6	4.75	213
320	89	39	11.6	18.4	4.45	214
288	85	43	11.4	16.5	4.25	215
268	82	46	16.1	21.0	4.10	216
468	102	26	9.8	16.0	5.1	217
456	101	27	10.7	16.8	5.05	218
360	93	35	14.7	20.3	4.65	219
560	106	22	8.4	14.8	5.30	221
496	102	25	5.7	11.9	5.15	222
528	104	24	6.3	12.6	5.20	223
570	106	22	5.8	12.2	5.30	224
482	102	26	6.8	13.0	5.10	225
466	101	27	5.9	12.0	5.05	226
464	101	27	8.4	14.5	5.05	227
354	93	35	10.2	15.8	4.65	228
432	99	29	8.6	14.6	4.95	229
456	101	27	7.8	13.9	5.05	230
328	90	38	11.1	16.5	4.50	231
322	90	38	10.6	16.0	4.50	232
320	89	39	13.4	18.7	4.45	233
492	103	25	9.6	15.8	5.15	234
468	102	26	9.9	16.1	5.10	235

TABLE III.—COMPOSITION OF THREE-PIGMENT

Paint No.	No. 1—Basic Lead Carbonate, lb.	No. 2—Basic Lead Carbonate, lb.	No. 3—Basic Lead Carbonate, lb.	No. 4—Zinc Oxide, lb.	No. 5—Zinc Oxide, lb.	No. 6—Basic Lead Sulphate, lb.	No. 7—Leaded Zinc Oxide, lb.	No. 8—Siliceous Material, lb.	No. 9—Silicate, lb.	No. 10—Clay, lb.	No. 11—Calcium Carbonate, lb.	No. 12—Calcium Sulphate, lb.	No. 13—Barium Sulphate, lb.
301	13.75	.....	.....	.....	11.25	13.00	.....	.....	.....	.....	.....	.....	.....
302	13.75	.....	.....	.....	11.25	.....	.....	5.50	.....	.....	.....	.....	.....
303	13.75	.....	.....	.....	11.25	.....	.....	.....	5.75	.....	.....	.....	.....
304	13.75	.....	.....	.....	11.25	.....	.....	.....	.....	5.50	.....	.....	.....
305	13.75	.....	.....	.....	11.25	.....	.....	.....	.....	.....	5.50	.....	.....
306	13.75	.....	.....	.....	11.25	.....	.....	.....	.....	.....	.....	4.75	.....
307	13.75	.....	.....	.....	11.25	.....	.....	.....	.....	.....	.....	.....	8.75
308	20.50	.....	.....	.....	8.50	9.75	.....	.....	.....	.....	.....	.....	.....
309	20.50	.....	.....	.....	8.50	.....	.....	4.00	.....	.....	.....	.....	.....
310	20.50	.....	.....	.....	8.50	.....	.....	.....	4.25	.....	.....	.....	.....
311	20.50	.....	.....	.....	8.50	.....	.....	.....	.....	4.00	.....	.....	.....
312	20.50	.....	.....	.....	8.50	.....	.....	.....	.....	.....	4.00	.....	.....
313	20.50	.....	.....	.....	8.50	.....	.....	.....	.....	.....	.....	3.50	.....
314	20.50	.....	.....	.....	8.50	.....	.....	.....	.....	.....	.....	.....	6.50
315	10.25	.....	.....	.....	16.75	9.75	.....	.....	.....	.....	.....	.....	.....
316	10.25	.....	.....	.....	16.75	.....	.....	4.00	.....	.....	.....	.....	.....
317	10.25	.....	.....	.....	16.75	.....	.....	.....	4.25	.....	.....	.....	.....
318	10.25	.....	.....	.....	16.75	.....	.....	.....	.....	4.00	.....	.....	.....
319	10.25	.....	.....	.....	16.75	.....	.....	.....	.....	.....	4.00	.....	.....
320	10.25	.....	.....	.....	16.75	.....	.....	.....	.....	.....	.....	3.50	.....
321	10.25	.....	.....	.....	16.75	.....	.....	.....	.....	.....	.....	.....	6.50
322	10.25	.....	.....	.....	8.50	19.75	.....	.....	.....	.....	.....	.....	.....
323	10.25	.....	.....	.....	8.50	.....	.....	8.25	.....	.....	.....	.....	.....
324	10.25	.....	.....	.....	8.50	.....	.....	.....	8.75	.....	.....	.....	.....
325	10.25	.....	.....	.....	8.50	.....	.....	.....	.....	8.25	.....	.....	.....
326	10.25	.....	.....	.....	8.50	.....	.....	.....	.....	.....	8.25	.....	.....
327	10.25	.....	.....	.....	8.50	.....	.....	.....	.....	.....	.....	7.00	.....
328	10.25	.....	.....	.....	8.50	.....	.....	.....	.....	.....	.....	.....	13.00
329	.....	.....	.....	.....	11.25	13.00	.....	5.50	.....	.....	.....	.....	.....
330	.....	.....	.....	.....	11.25	13.00	.....	.....	5.75	.....	.....	.....	.....
331	.....	.....	.....	.....	11.25	13.00	.....	.....	.....	5.50	.....	.....	.....
332	.....	.....	.....	.....	11.25	13.00	.....	.....	.....	.....	5.50	.....	.....
333	.....	.....	.....	.....	11.25	13.00	.....	.....	.....	.....	.....	4.75	.....
334	.....	.....	.....	.....	11.25	13.00	.....	.....	.....	.....	.....	.....	8.75
335	.....	.....	.....	.....	8.50	19.75	.....	4.00	.....	.....	.....	.....	.....
336	.....	.....	.....	.....	8.50	19.75	.....	.....	4.25	.....	.....	.....	.....
337	.....	.....	.....	.....	8.50	19.75	.....	.....	.....	4.00	.....	.....	.....
338	.....	.....	.....	.....	8.50	19.75	.....	.....	.....	.....	4.00	.....	.....
339	.....	.....	.....	.....	8.50	19.75	.....	.....	.....	.....	.....	3.50	.....
340	.....	.....	.....	.....	8.50	19.75	.....	.....	.....	.....	.....	.....	6.50

—COMPOSITION OF THREE-PIGMENT PAINTS.

No. 9—Silicate, lb.	No. 10—Clay, lb.	No. 11—Calcium Carbonate, lb.	No. 12—Calcium Sulphate, lb.	No. 13—Barium Sulphate, lb.	Ground in — Oz. of Oil.	Thinned with — Oz. of Oil.	Total Bulk of Paint, oz.	Volume of Oil, oz. per gal.	Volume of Pigment, oz. per gal.	Weight of Pigment per Gal., lb.	Weight of Paint per Gal., lb.	Drier, oz. per gal.	Paint No.
.....	.....	.....	.....	.....	136	208	410	100	28	11.1	18.1	5.00	301
.....	.....	.....	.....	.....	128	180	404	97	31	12.9	18.7	4.85	302
5.75	.....	.....	.....	.....	128	196	420	99	29	9.2	15.2	4.95	303
.....	5.50	.....	.....	.....	144	204	444	101	27	8.5	14.6	5.05	304
.....	.....	5.50	.....	.....	128	248	472	102	26	8.2	14.4	5.10	305
.....	.....	.....	4.75	.....	128	164	388	96	32	9.9	15.7	4.80	306
.....	.....	.....	.....	8.75	128	168	392	97	31	10.8	16.6	4.85	307
.....	.....	.....	.....	.....	128	208	432	99	29	11.6	17.6	4.95	308
.....	.....	.....	.....	.....	128	176	400	97	31	10.5	16.3	4.85	309
4.25	.....	.....	.....	.....	128	200	424	99	29	9.9	15.9	4.95	310
.....	4.00	.....	.....	.....	128	168	392	96	32	10.9	16.7	4.80	311
.....	.....	4.00	.....	.....	128	168	392	96	32	10.9	16.7	4.80	312
.....	.....	.....	3.50	.....	128	130	354	93	35	11.8	17.5	4.65	313
.....	.....	.....	.....	6.50	128	144	368	94	34	12.5	18.2	4.70	314
.....	.....	.....	.....	.....	144	248	472	102	26	10.5	16.7	5.10	315
.....	.....	.....	.....	.....	144	216	456	101	27	8.8	14.9	5.05	316
4.25	.....	.....	.....	.....	176	264	536	105	23	7.4	13.7	5.25	317
.....	4.00	.....	.....	.....	160	232	488	101	27	8.8	14.9	5.05	318
.....	.....	4.00	.....	.....	152	136	384	94	34	11.3	17.0	4.70	319
.....	.....	.....	3.50	.....	144	94	334	91	37	11.8	17.3	4.55	320
.....	.....	.....	.....	6.50	160	186	442	100	28	9.8	15.8	5.00	321
.....	.....	.....	.....	.....	144	164	404	97	31	12.3	18.1	4.85	322
.....	.....	.....	.....	.....	128	124	348	93	35	9.7	15.4	4.65	323
8.75	.....	.....	.....	.....	136	226	458	101	27	7.5	13.6	5.05	324
.....	8.25	.....	.....	.....	128	192	416	99	29	8.3	14.3	4.95	325
.....	.....	8.25	.....	.....	128	200	424	99	29	7.8	13.8	4.95	326
.....	.....	.....	7.00	.....	128	170	394	97	31	8.3	14.1	4.85	327
.....	.....	.....	.....	13.00	128	160	384	96	32	10.5	16.3	4.80	328
.....	.....	.....	.....	.....	144	194	434	100	28	8.7	14.7	5.00	329
5.75	.....	.....	.....	.....	144	240	480	102	26	8.2	14.4	5.10	330
.....	5.50	.....	.....	.....	128	244	468	102	26	8.2	14.4	5.10	331
.....	.....	5.50	.....	.....	128	234	458	101	27	8.4	14.7	5.05	332
.....	.....	.....	4.75	.....	128	216	440	100	28	8.5	14.5	5.00	333
.....	.....	.....	.....	8.75	128	216	440	100	28	9.6	15.6	5.00	334
.....	.....	.....	.....	.....	128	232	456	101	27	8.9	15.0	5.05	335
4.25	.....	.....	.....	.....	128	276	500	103	25	8.5	14.7	5.15	336
.....	4.00	.....	.....	.....	144	288	528	104	24	8.0	14.3	5.20	337
.....	.....	4.00	.....	.....	128	258	482	102	26	8.6	14.8	5.10	338
.....	.....	.....	3.50	.....	128	256	480	102	26	8.4	14.6	5.10	339
.....	.....	.....	.....	6.50	128	256	480	102	26	9.3	15.5	5.10	340

TABLE III.—COMPOSITION OF THREE-PIGMENT PAI

Paint No.	No. 1—Basic Lead Carbonate, lb.	No. 2—Basic Lead Carbonate, lb.	No. 3—Basic Lead Carbonate, lb.	No. 4—Zinc Oxide, lb.	No. 5—Zinc Oxide, lb.	No. 6—Basic Lead Sulphate, lb.	No. 7—Leaded Zinc Oxide, lb.	No. 8—Siliceous Material, lb.	No. 9—Silicate, lb.	No. 10—Clay, lb.	No. 11—Calcium Carbonate, lb.	No. 12—Calcium Sulphate, lb.	No. 13—Barium Sulphate, lb.
341	.....	.....	.....	.....	16.75	9.75	.....	4.00	.....	.....	.....	.....	.....
342	.....	.....	.....	.....	16.75	9.75	.....	.....	4.25	.....	.....	.....	.....
343	.....	.....	.....	.....	16.75	9.75	.....	.....	.....	4.00	.....	.....	.....
344	.....	.....	.....	.....	16.75	9.75	.....	.....	.....	.....	4.00	.....	.....
345	.....	.....	.....	.....	16.75	9.75	.....	.....	.....	.....	.....	3.50	.....
346	.....	.....	.....	.....	16.75	9.75	.....	.....	.....	.....	.....	.....	6.50
347	13.75	.....	.....	.....	.....	13.00	.....	5.50	.....	.....	.....	.....	.....
348	13.75	.....	.....	.....	.....	13.00	.....	.....	5.75	.....	.....	.....	.....
349	13.75	.....	.....	.....	.....	13.00	.....	.....	.....	5.50	.....	.....	.....
350	13.75	.....	.....	.....	.....	13.00	.....	.....	.....	.....	5.50	.....	.....
351	13.75	.....	.....	.....	.....	13.00	.....	.....	.....	.....	.....	4.75	.....
352	13.75	.....	.....	.....	.....	13.00	.....	.....	.....	.....	.....	.....	8.75
353	20.50	.....	.....	.....	.....	9.75	.....	4.00	.....	.....	.....	.....	.....
354	20.50	.....	.....	.....	.....	9.75	.....	.....	4.25	.....	.....	.....	.....
355	20.50	.....	.....	.....	.....	9.75	.....	.....	.....	4.00	.....	.....	.....
356	20.50	.....	.....	.....	.....	9.75	.....	.....	.....	.....	4.00	.....	.....
357	20.50	.....	.....	.....	.....	9.75	.....	.....	.....	.....	.....	3.50	.....
358	20.50	.....	.....	.....	.....	9.75	.....	.....	.....	.....	.....	.....	6.50
359	10.25	.....	.....	.....	.....	19.75	.....	4.00	.....	.....	.....	.....	.....
360	10.25	.....	.....	.....	.....	19.75	.....	.....	4.25	.....	.....	.....	.....
361	10.25	.....	.....	.....	.....	19.75	.....	.....	.....	4.00	.....	.....	.....
362	10.25	.....	.....	.....	.....	19.75	.....	.....	.....	.....	4.00	.....	.....
363	10.25	.....	.....	.....	.....	19.75	.....	.....	.....	.....	.....	3.50	.....
364	10.25	.....	.....	.....	.....	19.75	.....	.....	.....	.....	.....	.....	6.50
365	10.25	.....	.....	.....	.....	9.75	.....	8.25	.....	.....	.....	.....	.....
366	10.25	.....	.....	.....	.....	9.75	.....	.....	8.75	.....	.....	.....	.....
367	10.25	.....	.....	.....	.....	9.75	.....	.....	.....	8.25	.....	.....	.....
368	10.25	.....	.....	.....	.....	9.75	.....	.....	.....	.....	8.25	.....	.....
369	10.25	.....	.....	.....	.....	9.75	.....	.....	.....	.....	.....	7.00	.....
370	10.25	.....	.....	.....	.....	9.75	.....	.....	.....	.....	.....	.....	13.00

TABLE IV.—COMPOSITION OF FOUR-PIGMEN

401	10.25	.....	.....	.....	8.50	9.75	.....	4.00	.....	.....	.....	.....	.....
402	10.25	.....	.....	.....	8.50	9.75	.....	.....	4.25	.....	.....	.....	.....
403	10.25	.....	.....	.....	8.50	9.75	.....	.....	.....	4.00	.....	.....	.....
404	10.25	.....	.....	.....	8.50	9.75	.....	.....	.....	.....	4.00	.....	.....
405	10.25	.....	.....	.....	8.50	9.75	.....	.....	.....	.....	.....	3.50	.....
406	10.25	.....	.....	.....	8.50	9.75	.....	.....	.....	.....	.....	.....	6.50

POSITION OF THREE-PIGMENT PAINTS (*Continued*).

No. 9—Silicate, lb.	No. 10—Clay, lb.	No. 11—Calcium Carbonate, lb.	No. 12—Calcium Sulphate, lb.	No. 13—Barium Sulphate, lb.	Ground in — Oz. of Oil.	Thinned with — Oz. of Oil.	Total Bulk of Paint, oz.	Volume of Oil, oz. per gal.	Volume of Pigment, oz. per gal.	Weight of Pigment per Gal., lb.	Weight of Paint per Gal., lb.	Drier, oz. per gal.	Paint No.
.....	.....	.....	.....	.....	144	256	496	103	25	7.9	14.1	5.15	341
4.25	.....	.....	.....	.....	128	320	544	105	23	7.3	13.6	5.25	342
....	4.00	.....	.....	.....	128	296	520	104	24	7.6	13.9	5.20	343
....	.....	4.00	.....	.....	128	296	520	104	24	7.6	13.9	5.20	344
....	.....	.....	3.50	.....	128	292	516	104	24	7.5	13.8	5.20	345
....	.....	.....	.....	6.50	128	336	550	107	21	7.2	13.7	5.35	346
....	.....	.....	.....	.....	96	128	320	89	39	13.2	18.5	4.45	347
5.75	.....	.....	.....	.....	96	240	432	99	29	9.7	15.7	4.95	348
....	5.50	.....	.....	.....	96	208	400	97	31	10.3	16.1	4.85	349
....	.....	5.50	.....	.....	96	200	392	97	31	10.3	16.1	4.85	350
....	.....	.....	4.75	.....	96	144	336	92	36	11.8	17.4	4.60	351
....	.....	.....	.....	8.75	96	146	338	92	36	13.6	19.2	4.60	352
....	.....	.....	.....	.....	96	146	338	92	36	12.9	18.5	4.60	353
4.25	.....	.....	.....	.....	96	178	370	94	34	12.3	18.0	4.70	354
....	4.00	.....	.....	.....	88	193	377	95	33	11.8	17.6	4.75	355
....	.....	4.00	.....	.....	88	155	339	92	36	12.9	18.5	4.60	356
....	.....	.....	3.50	.....	80	153	329	92	36	12.7	18.3	4.70	357
....	.....	.....	.....	6.50	96	178	370	94	34	13.1	18.8	4.70	358
....	.....	.....	.....	.....	96	172	364	94	34	12.0	17.8	4.70	359
4.25	.....	.....	.....	.....	96	222	414	98	30	10.6	16.6	4.90	360
....	4.00	.....	.....	.....	96	226	418	98	30	10.6	16.6	4.90	361
....	.....	4.00	.....	.....	96	192	384	95	33	11.6	17.4	4.75	362
....	.....	.....	3.50	.....	96	161	353	93	35	12.1	17.8	4.65	363
....	.....	.....	.....	6.50	96	160	352	93	35	13.2	19.0	4.65	364
....	.....	.....	.....	.....	96	168	360	94	34	10.0	15.7	4.70	365
8.75	.....	.....	.....	.....	100	216	412	98	30	9.0	14.9	4.90	366
....	8.25	.....	.....	.....	100	160	356	93	35	10.2	15.9	4.65	367
....	.....	8.25	.....	.....	96	152	344	92	36	10.7	16.3	4.60	368
....	.....	.....	7.00	.....	96	138	330	91	37	10.1	15.6	4.55	369
....	.....	.....	.....	13.00	96	128	310	92	36	12.6	18.2	4.60	370

—COMPOSITION OF FOUR-PIGMENT PAINTS.

....	.....	....	.....	.....	108	188	392	99	29	9.7	15.7	4.95	401
4.25	.....	.....	.....	.....	128	244	468	102	26	8.8	15.0	5.10	402
....	4.00	.....	.....	.....	128	232	456	102	26	8.8	15.0	5.10	403
....	.....	4.00	.....	.....	128	192	416	99	29	9.7	15.7	4.95	404
....	.....	.....	3.50	.....	128	192	416	89	29	9.6	15.6	4.95	405
....	.....	.....	.....	6.50	128	206	432	100	28	10.2	16.3	5.00	406

Rogers found that these three paints had about the same consistency as measured by the Stormer viscosimeter. He then found that 95-per-cent glycerin at 20° C. had practically the same consistency as the three standard paints. The Stormer viscosimeter was then adjusted so that it required two minutes for a complete rotation of the pointer in 95-per-cent glycerin at 20° C. The paints used were then made up by adding oil in fractions and making viscosity determinations after each addition, until the viscosity was 10 points greater than the standard; that is, until the dial went to 90 instead of 100 in two minutes. Tables I to IV (Plates IX, X and XI) give the final composition of the paints. Samples of these paints were

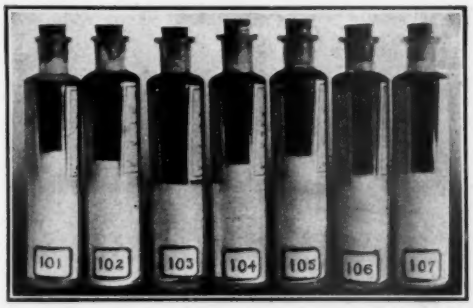


FIG. 1.—Single-Pigment Paints.

preserved in glass bottles and photographs taken at the end of about six months. Paints Nos. 212, 213 and 218 stuck to the sides of the bottles, but the others show the relative settling of the different paints very well. Figs. 1, 2 and 3 are reproductions of the photographs.

The paints were applied on both sides of the yellow poplar test boards 8 by 1 by 36 in., properly numbered by branding before painting. For the first coat, the paint as received from the Pratt Institute was thinned with a mixture of seven parts linseed oil and one part turpentine. This thinner was added to one quart of each paint on the basis of 1½ pints of thinner to one gallon of paint. The first coat was spread as evenly as possible and ran about 650 sq. ft. to the gallon. On the first and second coats both sides of each board and all the edges were

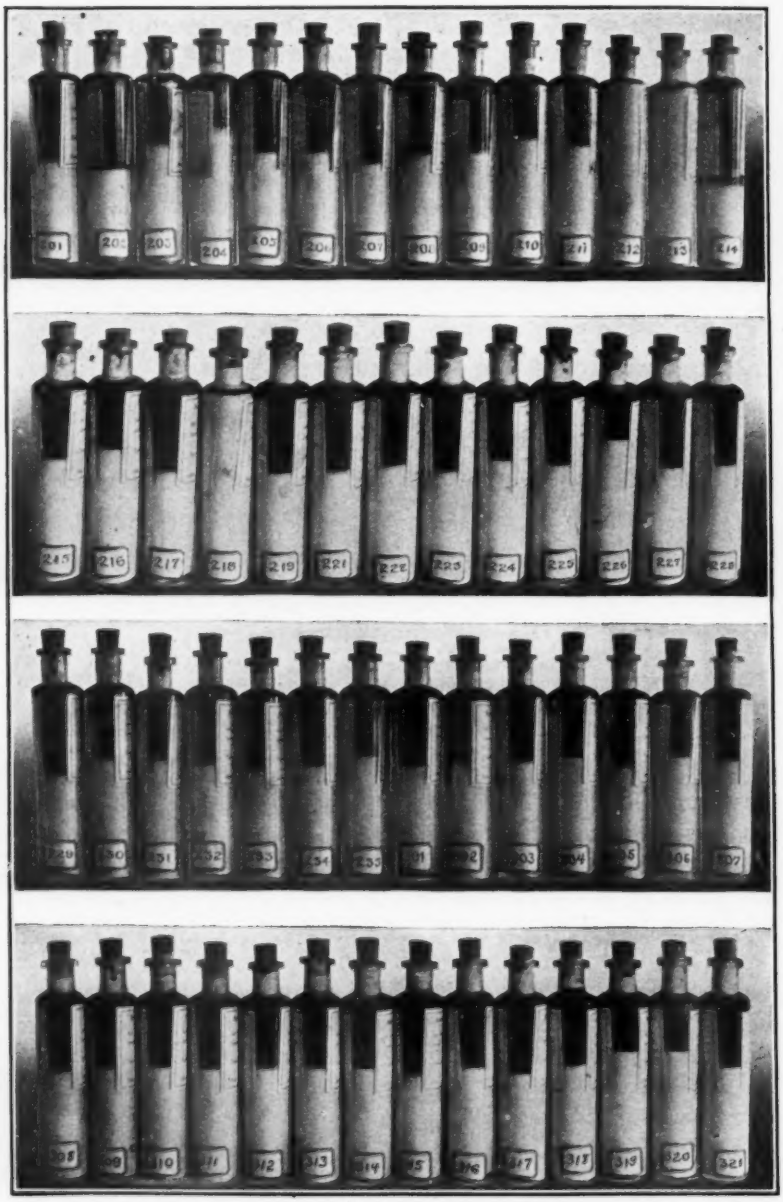


FIG. 2. { Nos. 201–235, Two-Pigment Paints.
Nos. 301–321, Three-Pigment Paints.



FIG. 3. { Nos. 321–370, Three-Pigment Paints.
Nos. 401–406, Four-Pigment Paints.

painted. Before the third coat was applied the test boards were made into panels, three boards to a panel, by nailing strips $\frac{3}{4}$ by $1\frac{1}{2}$ by 24 in. on the ends of the boards. These panels, two panels of each number, were then painted on both sides and the exposed edges. The panels were crated and shipped by freight

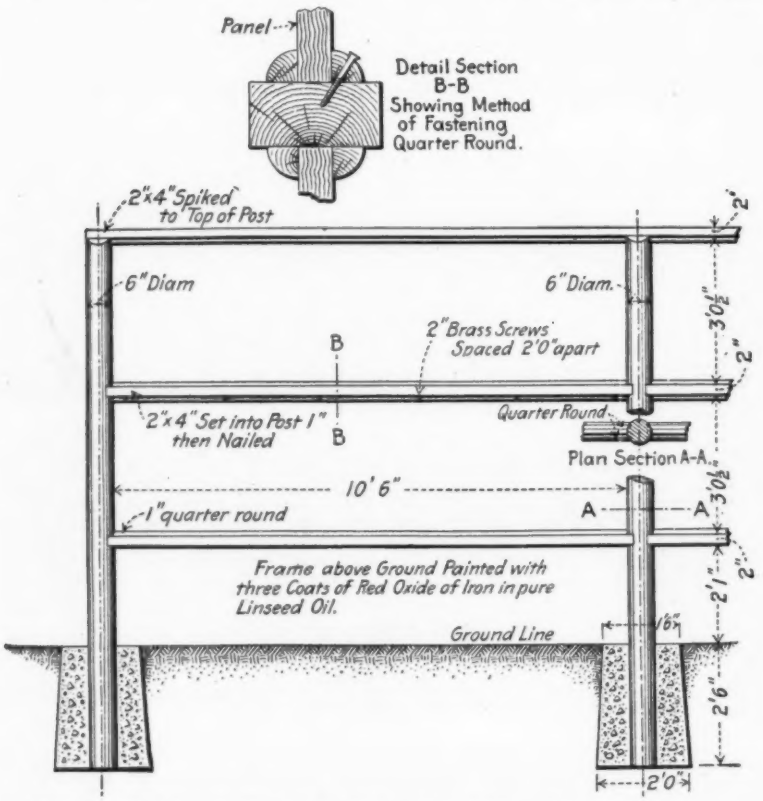


FIG. 4.—Showing Construction of Frame and Mounting of Test Pieces.

from Baltimore to Washington and hauled by wagon from Washington to the site of the exposure frame on the Experiment Farm of the United States Department of Agriculture at Arlington, Virginia. The method of paneling and crating adopted was a very efficient means of protecting the test pieces from injury in transit, and they were all received in good condition.

The frame for exposing the test pieces is located on the Arlington Farm, on a plot of ground south of the Miscellaneous Garden and east of the track of the Washington Southern Railroad. The railroad is above the level of the site of the frame. To the east of the frame is a marsh which is sometimes overflowed, but the frame is on ground sufficiently high to be safe from overflow. The frame runs north and south, consists of 26 panels, and is constructed as follows: Posts of red cedar 10 ft. 10½ in. long and 6 in. in diameter, are planted 2½ ft. deep in

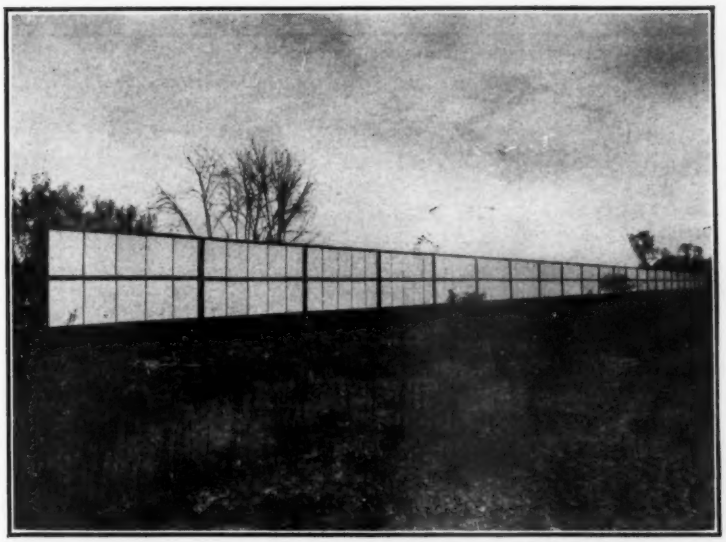


FIG. 5.—Completed Test Fence.

1 : 2 : 3 concrete, and spaced 10 ft. 6 in. in the clear between posts. The posts are connected by three lines of 2 by 4-in. dressed Georgia pine stringers, the top stringers spiked to the tops of the posts, the middle and bottom stringers notched in and spiked with a clearance of 36½ in. The test pieces are attached to the frame by 1-in. quarter-round molding fastened by 2-in. brass screws. Fig. 4 shows the construction of the frame and method of mounting the test pieces. The frame and strips of molding were painted with three coats of red oxide of iron in linseed oil.

The crates containing the test pieces were opened on the ground near the frame, the end strips carefully removed, and the test pieces placed in the frame in the manner indicated above, so that duplicates are in vertical columns. The three boards constituting one test were placed next to one another in the frame, but narrow strips of white pine were used to separate the different tests. These strips are unpainted. Paint No. 101 is exposed on the north end of the frame and the succeeding paints extend south.

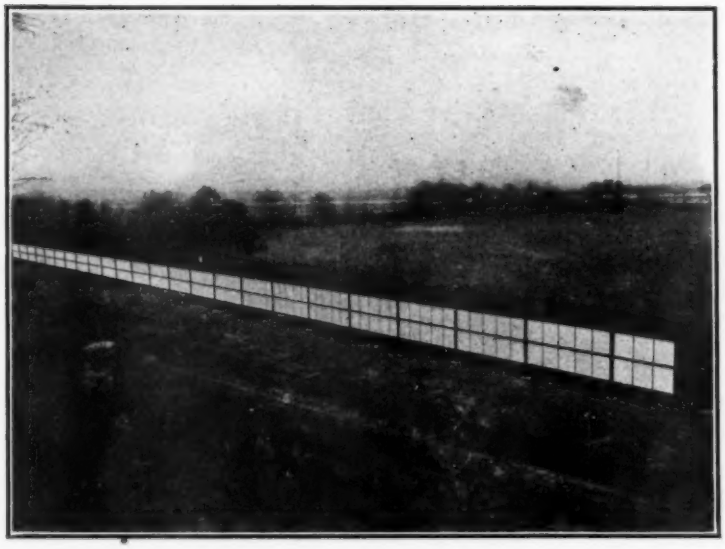


FIG. 6.—Completed Test Fence.

The painting was finished about July 15, 1912, and the boards were placed in position on the frame during the week ending August 31, 1912.

Figs. 5 and 6 are reproduced from photographs of the completed fence taken early in November, 1912.

Further tests of the pigments used, the results of which were received subsequent to the preparation of the above, are given below.

CLASSIFICATION TESTS OF PIGMENTS USED.

The thirteen pigments used in this test have been classified by the Thompson classifier[1] in the laboratory of the National Lead Co., and the results are given in Table V.

TABLE V.—CLASSIFICATION OF FINE PARTICLES.

	Sample No. 1.—Basic Lead Carbonate (Dutch Process White Lead).	Sample No. 2.—Basic Lead Carbonate (Carter White Lead).	Sample No. 3.—Basic Lead Carbonate (Mild Process White Lead).	Sample No. 4.—Zinc Oxide (Florence Green Seal French Process Zinc Oxide).	Sample No. 5.—Zinc Oxide (XX American Process Zinc Oxide).	Sample No. 6.—Basic Lead Sulphate (Sublimed White Lead).
Coarse Portion.....	trace	trace	trace	trace	trace	none
Cone No. 1.....	6.1	5.1	3.7	1.8	0.3	0.9
Cone No. 2.....	0.6	2.5	0.5	6.5	0.9	0.7
Cone No. 3.....	5.6	2.7	2.0	5.7	2.1	2.1
Cone No. 4.....	8.2	4.3	4.5	9.6	3.1	3.2
Portion No. 5.....	79.5	85.4	89.3	76.4	93.6	93.1
Total.....	100.0	100.0	100.0	100.0	100.0	100.0

All values are percentages.

TABLE V.—CLASSIFICATION OF FINE PARTICLES (*Continued*).

	Sample No. 7.—Leaded Zinc Oxide (Leaded Oxide of Zinc).	Sample No. 8.—Siliceous Material (Silica).	Sample No. 9.—Silicate (Asbestine).	Sample No. 10.—Clay (L. G. V. China Clay).	Sample No. 11.—Calcium Carbonate (Extra Gilders Whiting, Bolted).	Sample No. 12.—Calcium Sulphate.	Sample No. 13.—Barium Sulphate (Cream Floated Lead Bloom—Water Floated Barytes).
Coarse Portion.	none	1.8	4.8	trace	0.3	8.7	trace
Cone No. 1....	0.2	16.8	17.8	0.9	2.5	16.4	13.2
Cone No. 2....	0.5	13.1	6.7	5.5	1.9	5.7	14.2
Cone No. 3....	1.3	7.6	9.5	9.5	5.4	7.0	13.0
Cone No. 4....	3.7	12.0	10.6	10.7	7.7	14.0	10.8
Portion No. 5..	94.3	48.7	50.6	73.4	82.2	48.2	48.8
Total.....	100.0	100.0	100.0	100.0	100.0	100.0	100.0

All values are percentages.

[1] For a description of this classifier, see "The Classification of Fine Particles According to Size," by G. W. Thompson, *Proceedings*, Am. Soc. Test. Mats., Vol. X, p. 601 (1910).

"Coarse portion," as here termed, is the material which will not pass through a No. 21 silk bolting cloth screen. "Portion No. 5" is obtained by difference. In each case the flow of kerosene was varied according to the specific gravity of the pigment. The amount used was likewise varied.

Microphotographs of the original pigments and the various classified portions were made in the Microchemical Laboratory of the Bureau of Chemistry and appear as Figs. 7 to 92 (pages 434–447). They were all made by transmitted light with a magnification of 200 diameters.

The following comments are made by the Microchemical Laboratory:

"Most of the pictures were taken from mounts of the powder with linseed oil. A few, however, were mounted in Canada balsam; and from the results obtained, better results might have been obtained had Canada balsam been used on all the samples. This would have been of particular advantage with pigments Nos. 1 to 7, inclusive, for it appears that there is less tendency to flocculate in Canada balsam than in linseed oil.

"Another point to which attention should be called is that in many of the samples of pigments Nos. 1 to 7, there were fairly large particles mixed with much fine material, and an examination of the larger particles indicates that they were usually aggregates of the small ones. Therefore, in making the mounts many of these large particles broke up into finer portions and the pictures may not show the state of aggregation of the particles as they originally came from the separating cones. This is of vital importance in making a series of pictures such as the present one, where it is the purpose to obtain representation of the size of the particles, and it is believed that about the only way to get satisfactory pictures is to mount and photograph the substance directly as it comes from the cones, as the subsequent washing and drying is likely to produce aggregation, making later examination uncertain. In making this series of pictures we have sought to make as accurate representations as possible, but we feel that they may not represent truthfully the size of the particles or aggregates as they came originally from the cones.

"In many samples it seems that the pieces are aggregates rather than individual particles. In the first place, an exami-

nation at about 200 magnifications shows the particles irregular, with rough edges, as if finer portions were sticking to them. This is shown well in Fig. 89. Also, in this, as in the others, there is abundance of small fine particles throughout the field. It seems difficult to explain why these were not carried into the cones with small particles if they had been free at the time, for they are no larger than those that are carried over.

"Attention is called to the fact that as soon as the cover glass on a mount is moved laterally the larger aggregates begin disintegrating, leaving a trail of small particles behind. (See Fig. 90.)

"Fig. 91 shows a larger aggregate that has broken up into a number of intermediate-size aggregates as well as many fine particles.

"If the pressing and moving of the cover glass is continued the large particles continue to disintegrate until the appearance is obtained, as shown in Fig. 92, which is an average view on the slide. All of this set (Figs. 89, 90, 91 and 92) showing these points were made from the same slide at different stages of disintegration. Again, the shape of the particles as they disintegrate indicates that they are disintegration particles rather than portions broken off from a solid or porous body.

"On the most of the other samples, especially the silica, asbestine and calcium sulphate, the particles seem to have been quite evenly graded, and hence give much more satisfactory photographs."

Respectfully submitted on behalf of the sub-committee,

PERCY H. WALKER,
Chairman

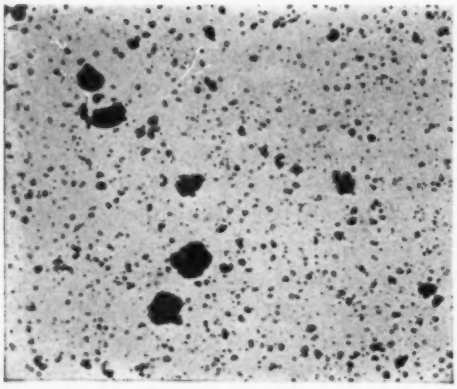


FIG. 7.—Original.

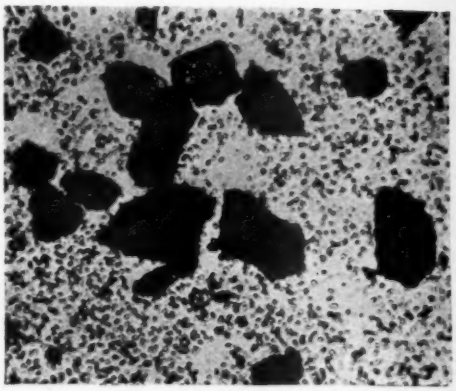


FIG. 8.—Cone No. 1.

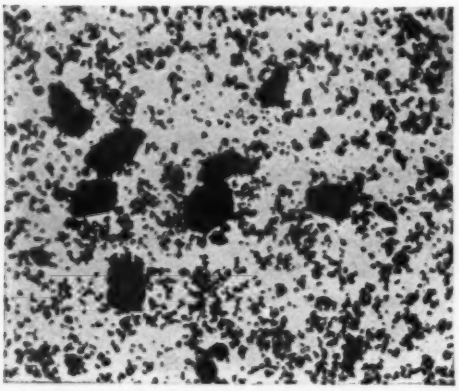


FIG. 9.—Cone No. 2.

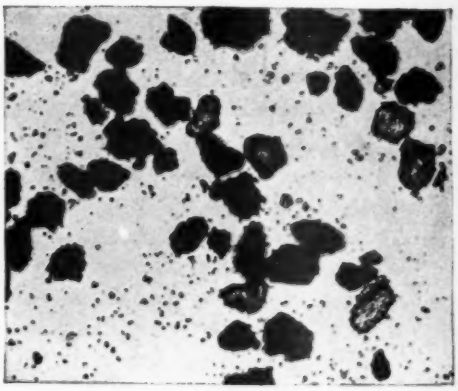


FIG. 10.—Cone No. 3.

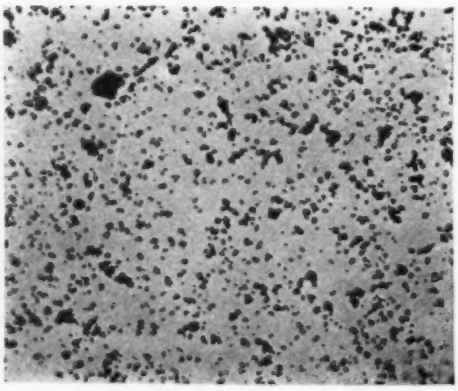


FIG. 11.—Cone No. 4.

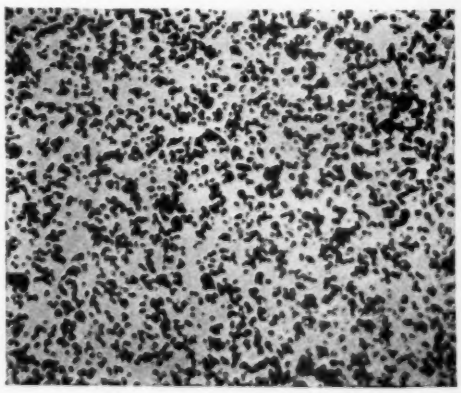


FIG. 12.—Portion No. 5.

SAMPLE NO. 1.—BASIC LEAD CARBONATE (DUTCH PROCESS WHITE LEAD) × 200.

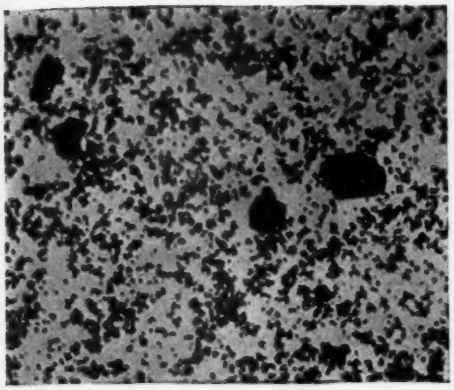


FIG. 13.—Original.

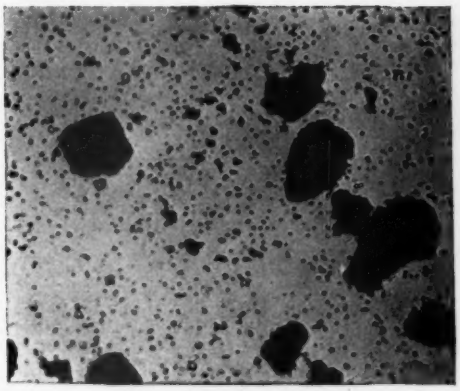


FIG. 14.—Cone No. 1.

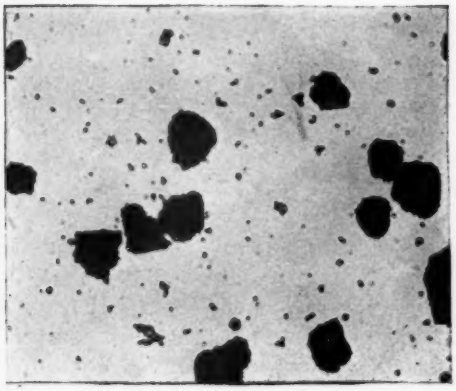


FIG. 15.—Cone No. 2.

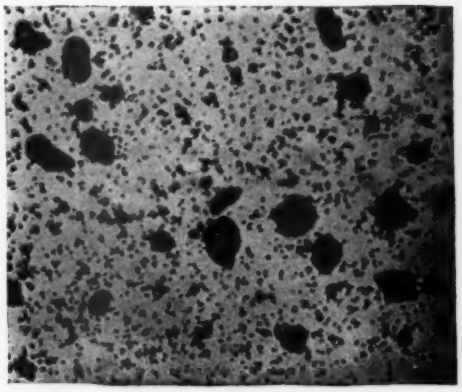


FIG. 16.—Cone No. 3.

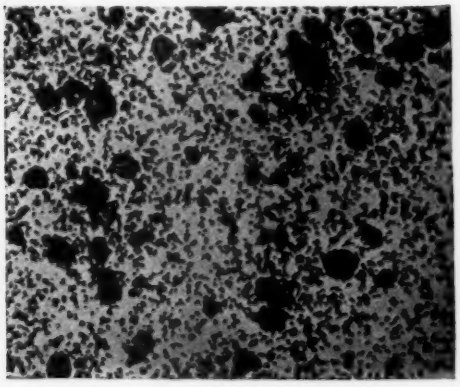


FIG. 17.—Cone No. 4.

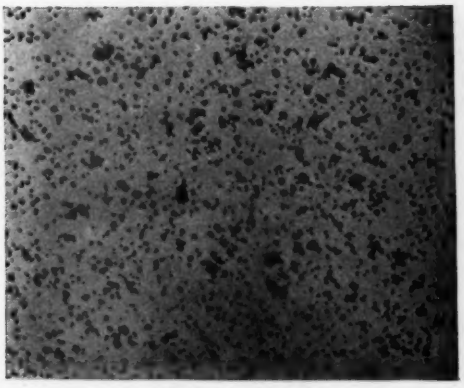


FIG. 18.—Portion No. 5.

SAMPLE NO. 2.—BASIC LEAD CARBONATE (CARTER WHITE LEAD) × 200.

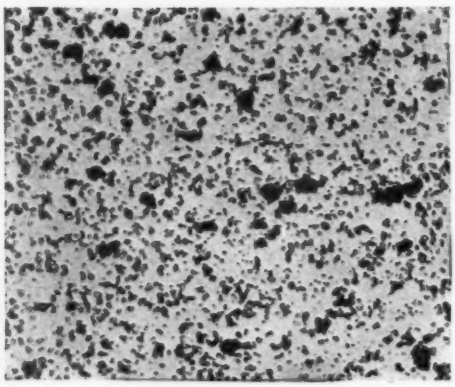


FIG. 19.—Original.

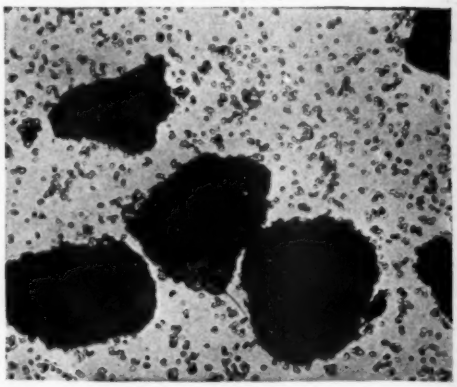


FIG. 20.—Cone No. 1.

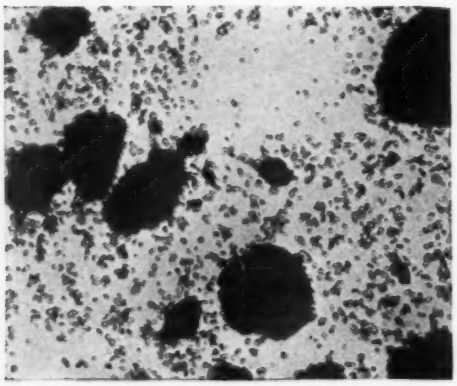


FIG. 21.—Cone No. 2.

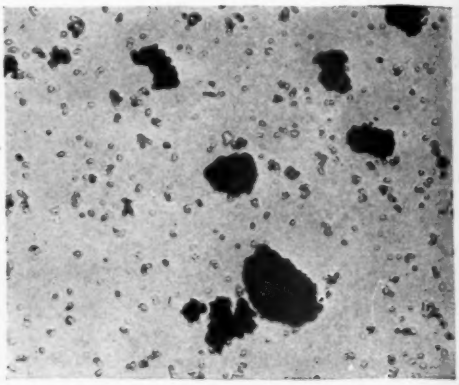


FIG. 22.—Cone No. 3.

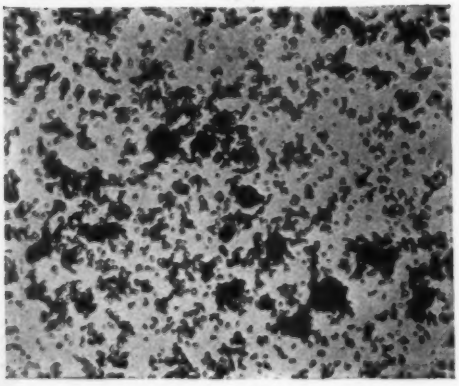


FIG. 23.—Cone No. 4.

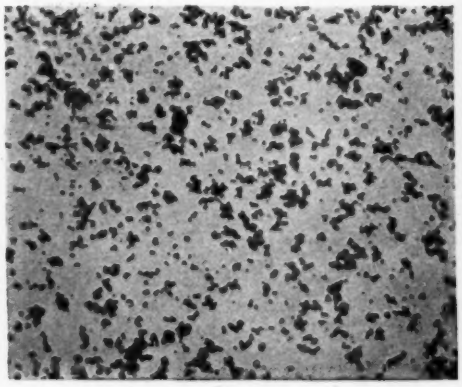


FIG. 24.—Portion No. 5.

SAMPLE NO. 3.—BASIC LEAD CARBONATE (MILD PROCESS WHITE LEAD) × 200.

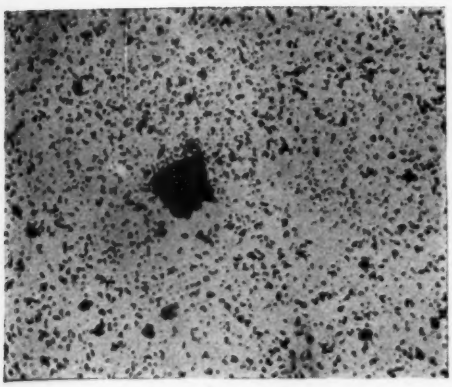


FIG. 25.—Original.

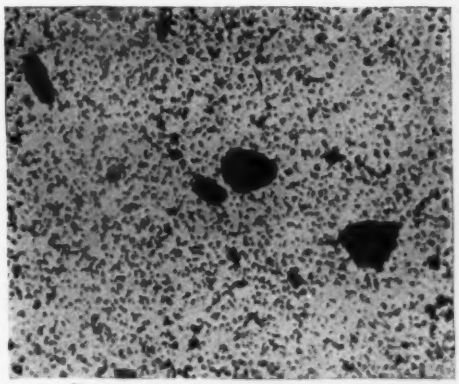


FIG. 26.—Cone No. 1.

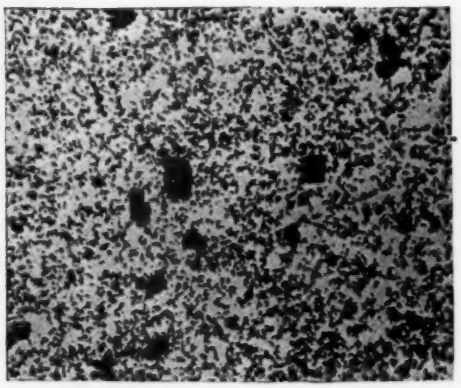


FIG. 27.— Cone No 2.

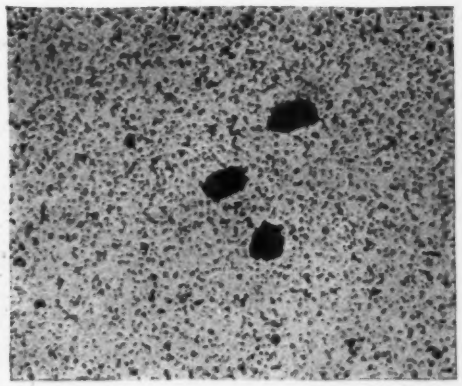


FIG. 28.—Cone No. 3.

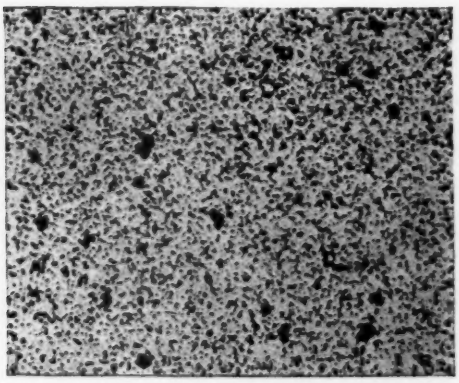


FIG. 29.—Cone No. 4.

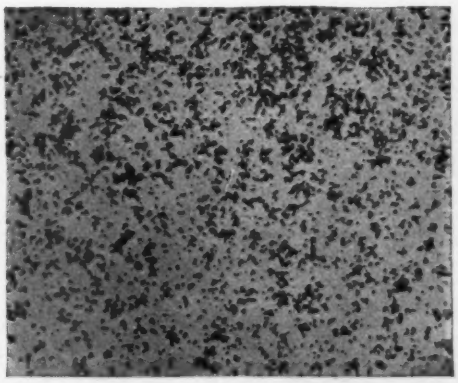


FIG. 30.—Portion No. 5.

SAMPLE NO. 4.—ZINC OXIDE (FLORENCE GREEN SEAL, FRENCH PROCESS ZINC OXIDE) × 200.

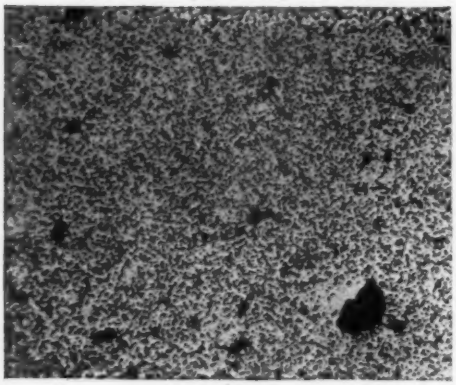


FIG. 31.—Original.

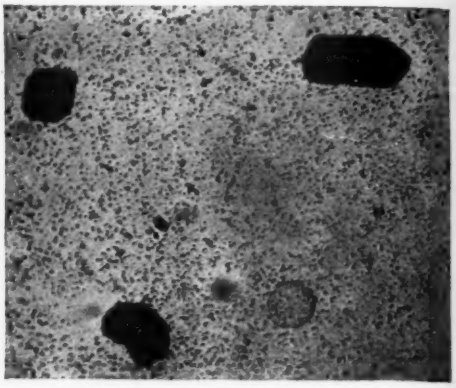


FIG. 32.—Cone No. 1.

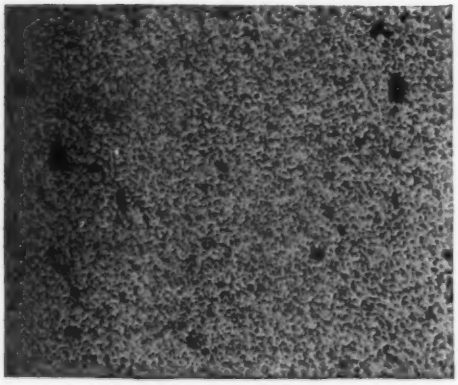


FIG. 33.—Cone No. 2

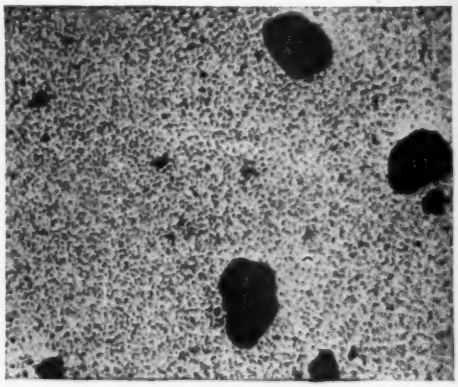


FIG. 34.—Cone No. 3.

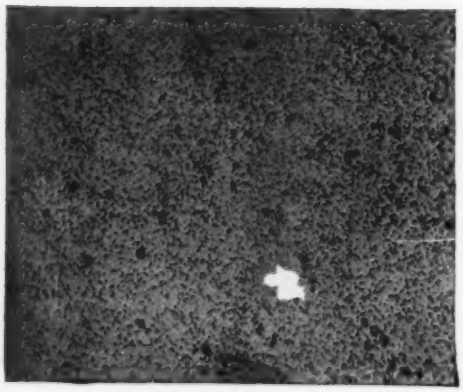


FIG. 35.—Cone No. 4.



FIG. 36.—Portion No. 5.

SAMPLE NO. 5.—ZINC OXIDE (XX AMERICAN PROCESS ZINC OXIDE) × 200.

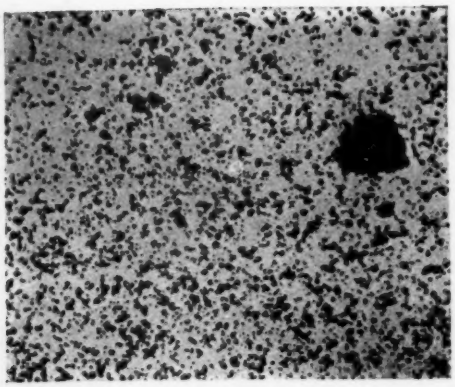


FIG. 37.—Original.

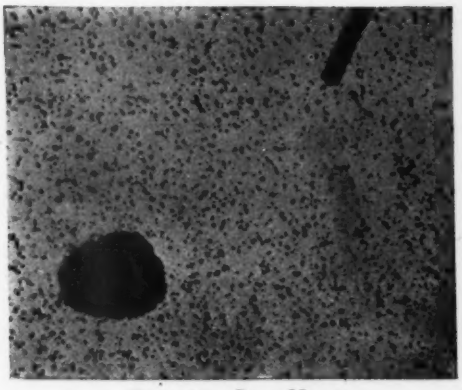


FIG. 38.—Cone No. 1.

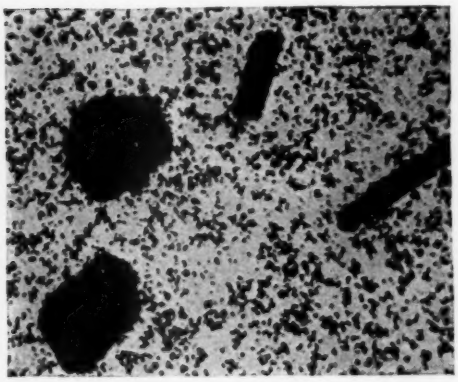


FIG. 39.—Cone No. 2.

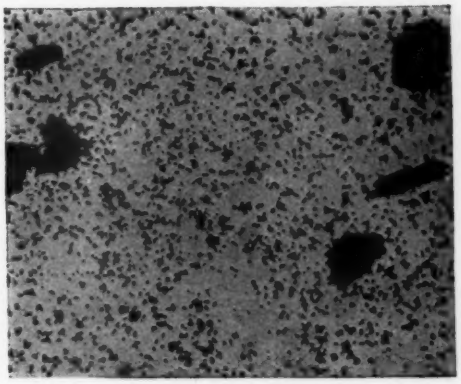


FIG. 40.—Cone No. 3.

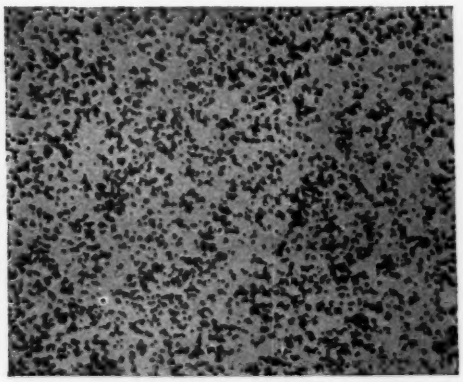


FIG. 41.—Cone No. 4.

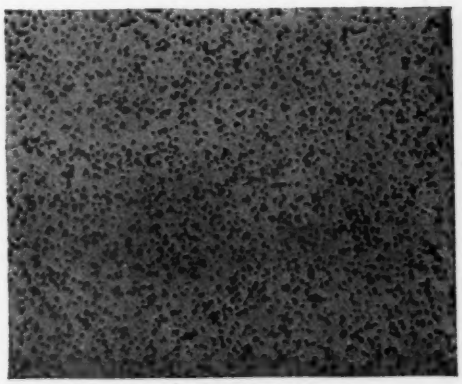


FIG. 42.—Portion No. 5.

SAMPLE NO. 6.—BASIC LEAD SULPHATE (SUBLIMED WHITE LEAD) × 200.

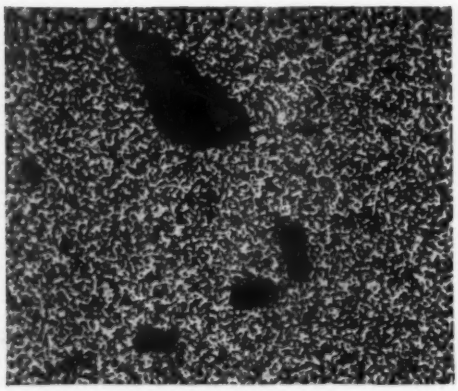


FIG. 43.—Original.



FIG. 44.—Cone No. 1.

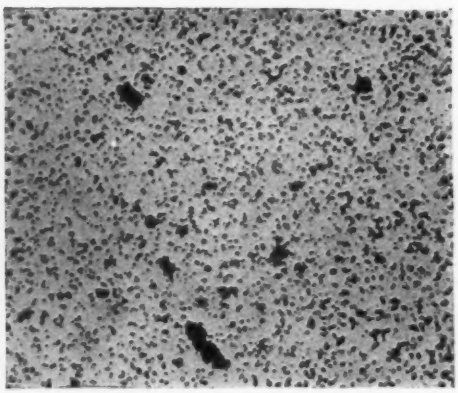


FIG. 45.—Cone No. 2.

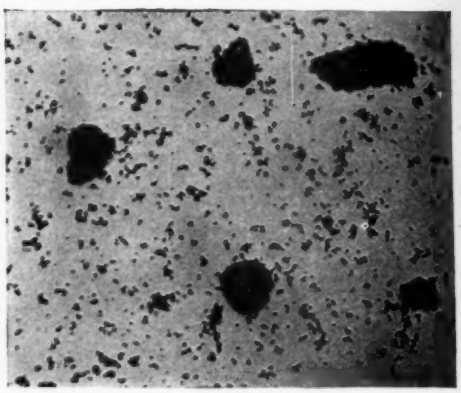


FIG. 46.—Cone No. 3.

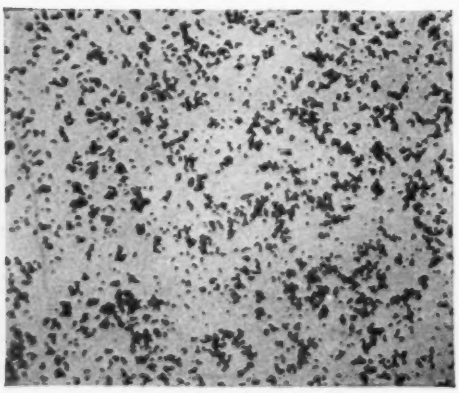


FIG. 47.—Cone No. 4.

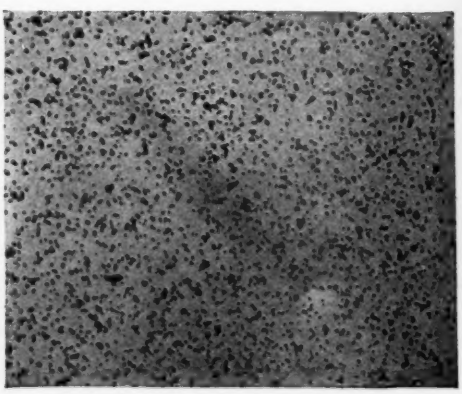


FIG. 48.—Portion No. 5.

SAMPLE NO. 7.—LEADED ZINC OXIDE (LEADED OXIDE OF ZINC) × 200.

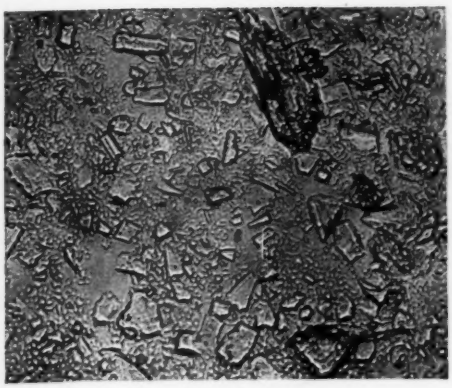


FIG. 49.—Original.

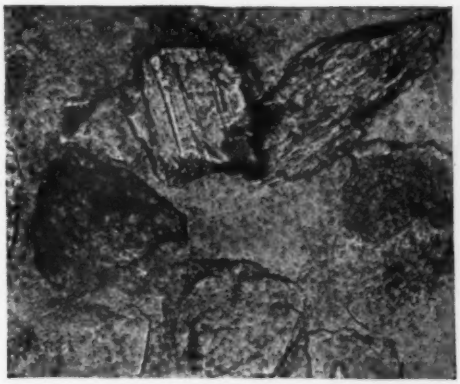


FIG. 50.—Coarse Portion.

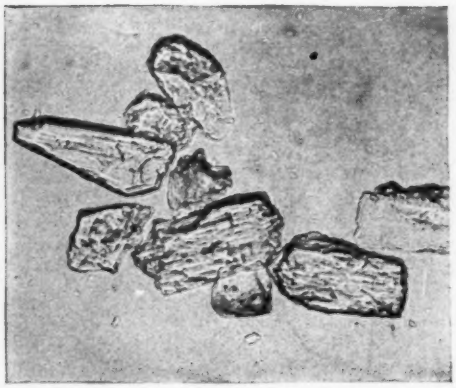


FIG. 51.—Cone No. 1.

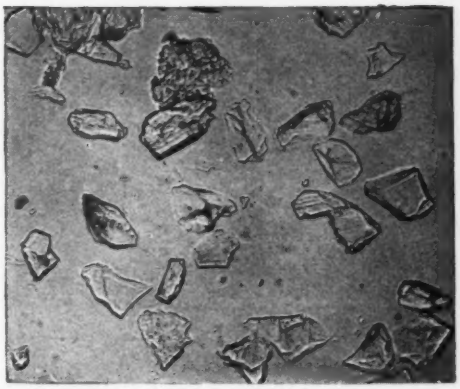


FIG. 52.—Cone No. 2.

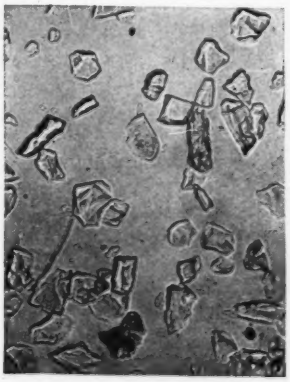


FIG. 53.—Cone No. 3.



FIG. 54.—Cone No. 4.

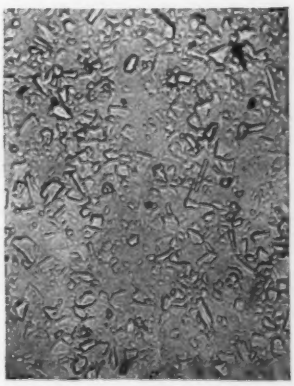


FIG. 55.—Portion No. 5.

SAMPLE NO. 8.—SILICEOUS MATERIAL (SILICA) × 200.

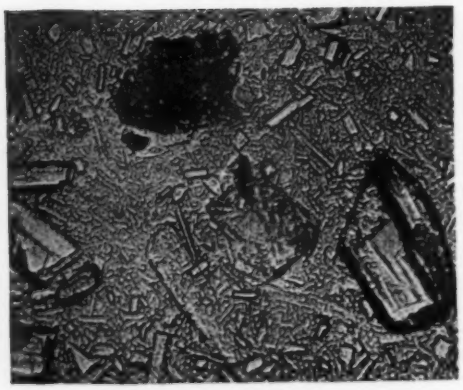


FIG. 56.—Original.

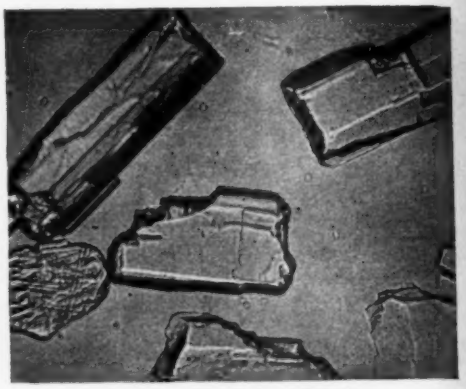


FIG. 57.—Coarse Portion.



FIG. 58.—Cone No. 1.

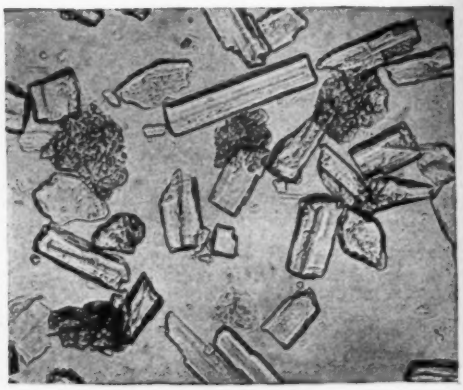


FIG. 59.—Cone No. 2.



FIG. 60.—Cone No. 3.

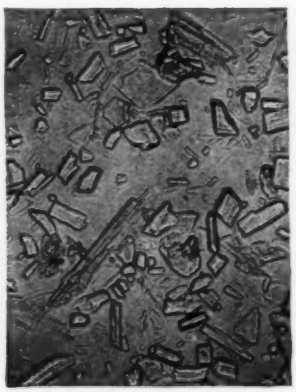


FIG. 61.—Cone No. 4.



FIG. 62.—Portion No. 5.

SAMPLE NO. 9.—SILICATE (ASBESTINE) × 200.

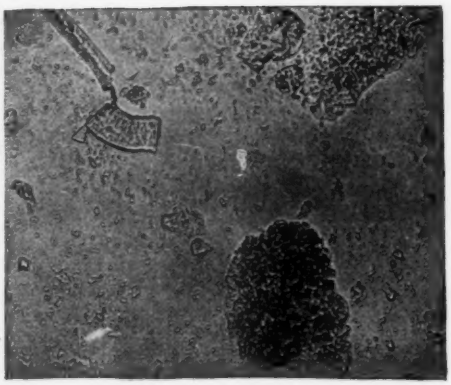


FIG. 63.—Original.

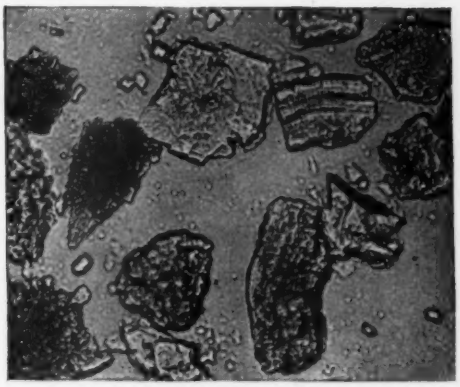


FIG. 64.—Cone No. 1.

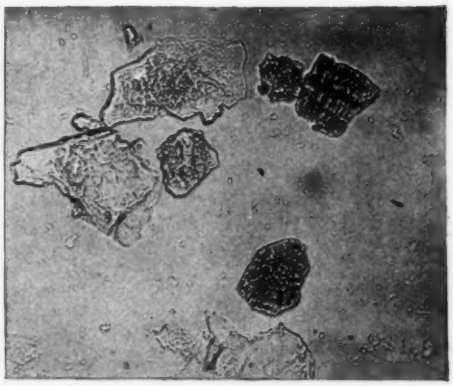


FIG. 65.—Cone No. 2.



FIG. 66.—Cone No. 3.

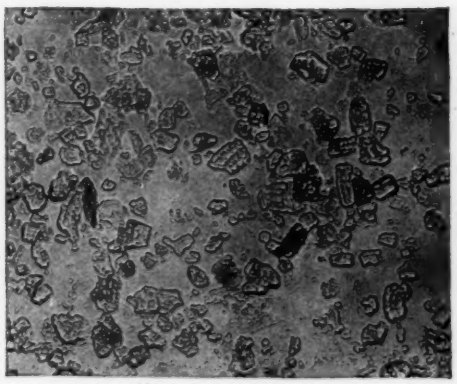


FIG. 67.—Cone No. 4.

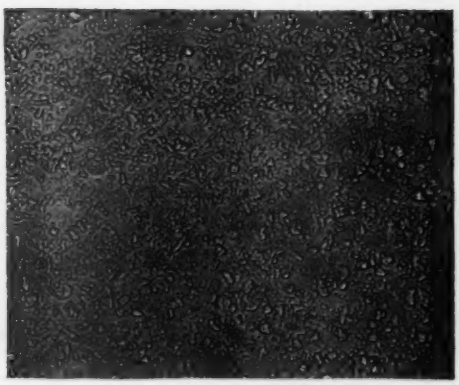


FIG. 68.—Portion No. 5.

SAMPLE NO. 10.—CLAY (L. G. V. CHINA CLAY) × 200.

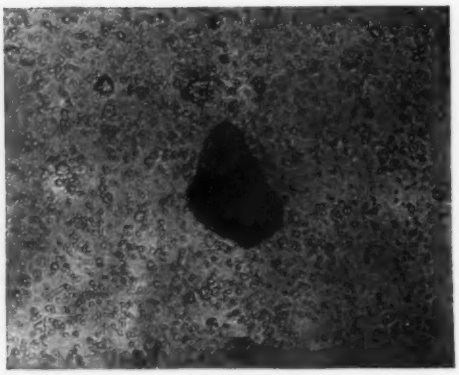


FIG. 69.—Original.

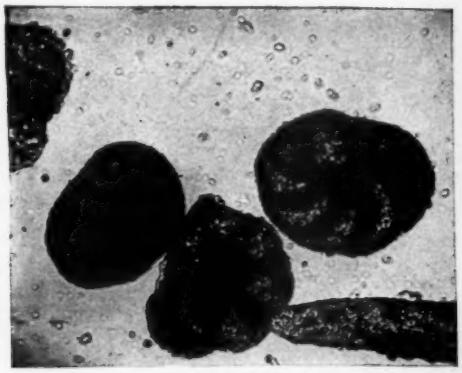


FIG. 70.—Coarse Portion.

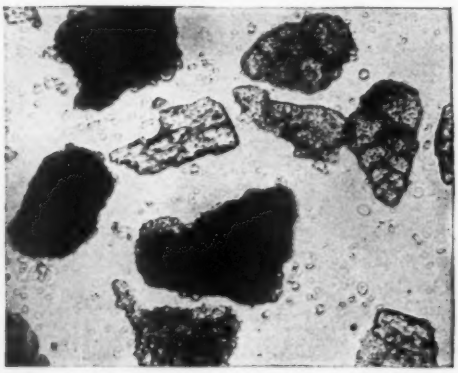


FIG. 71.—Cone No. 1.

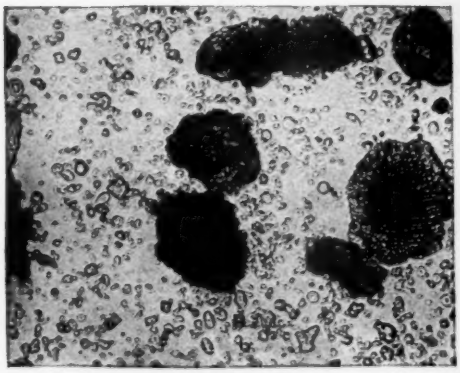


FIG. 72.—Cone No. 2.

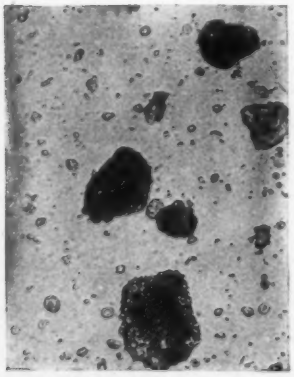


FIG. 73.—Cone No. 3.

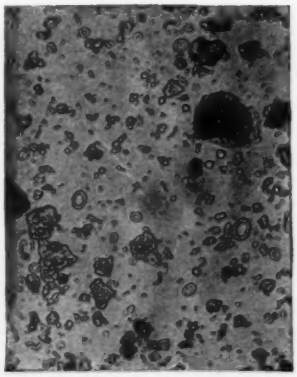


FIG. 74.—Cone No. 4.

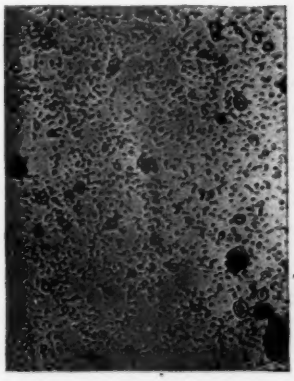


FIG. 75.—Portion No. 5.

SAMPLE NO. 11.—CALCIUM CARBONATE (EXTRA GILDERS WHITING, BOLTED) × 200.

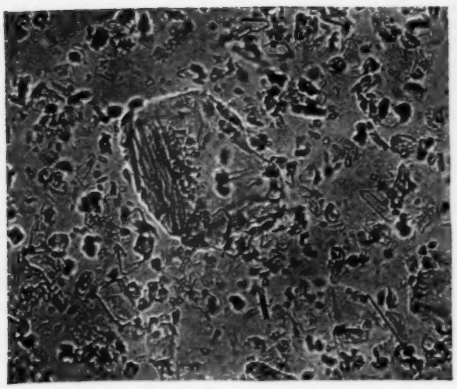


FIG. 76.—Original.

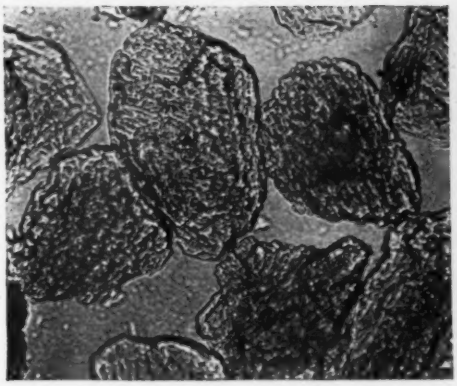


FIG. 77.—Coarse Portion

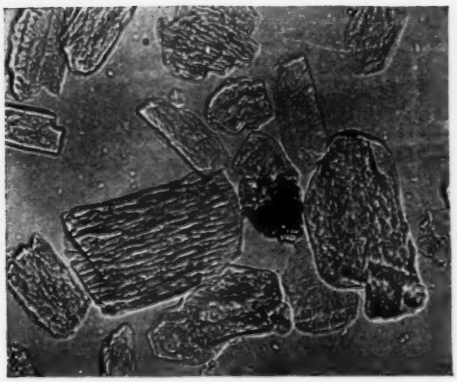


FIG. 78.—Cone No. 1.

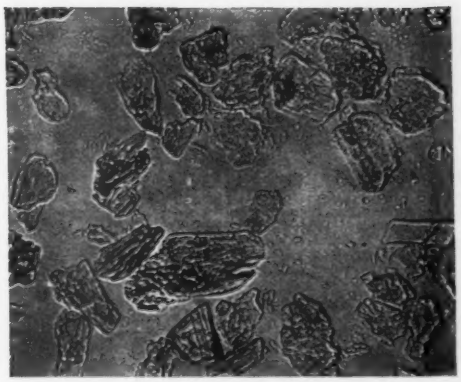


FIG. 79.—Cone No. 2.



FIG. 80.—Cone No. 3.

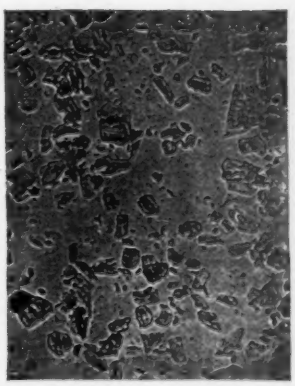


FIG. 81.—Cone No. 4.



FIG. 82.—Portion No. 5.

SAMPLE NO. 12.—CALCIUM SULPHATE × 200.

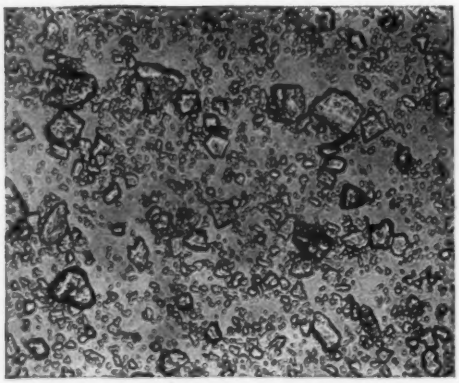


FIG. 83.—Original.

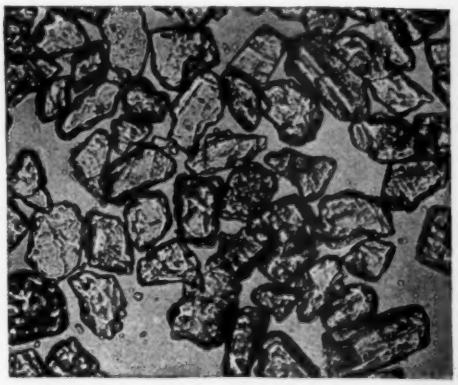


FIG. 84.—Cone No. 1.

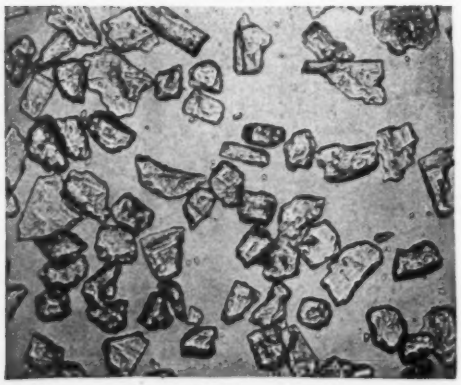


FIG. 85.—Cone No. 2.

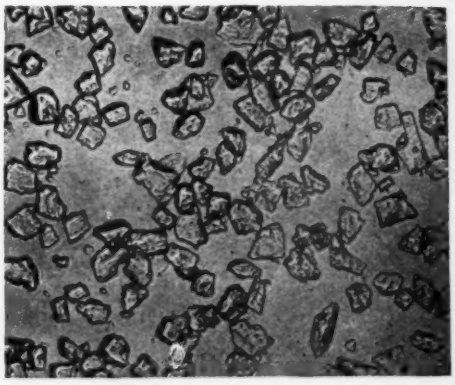


FIG. 86.—Cone No. 3.

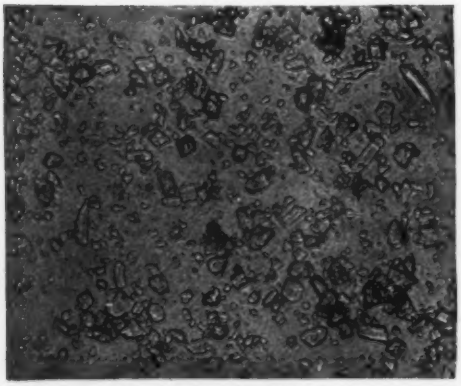


FIG. 87.—Cone No. 4.



FIG. 88.—Portion No. 5.

SAMPLE NO. 13.—BARIUM SULPHATE (CREAM FLOATED LEAD BLOOM, WATER-FLOATED BARYTES) × 200.

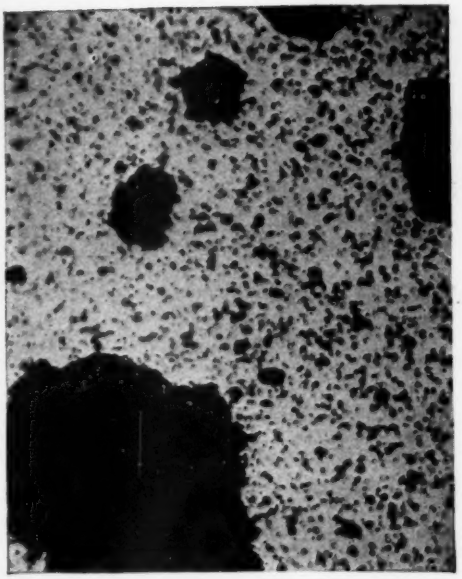


FIG. 89.—Sample No. 1, mounted on slide with as little breaking of particles as possible. Cone No. 2; × 200.

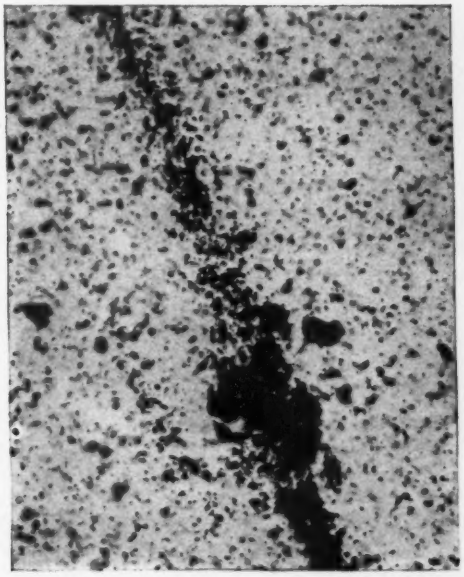


FIG. 90.—Same slide as shown in Fig. 89 but taken after cover glass had been moved, causing the aggregate to start breaking into component fine particles. × 200.

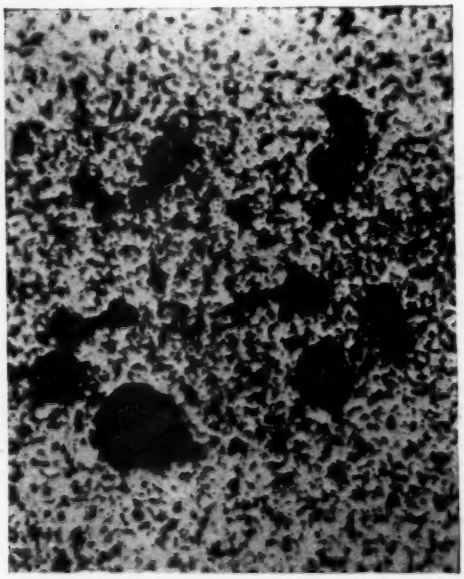


FIG. 91.—Same slide as shown in Fig. 89 but in which a larger piece is shown breaking up. × 200.

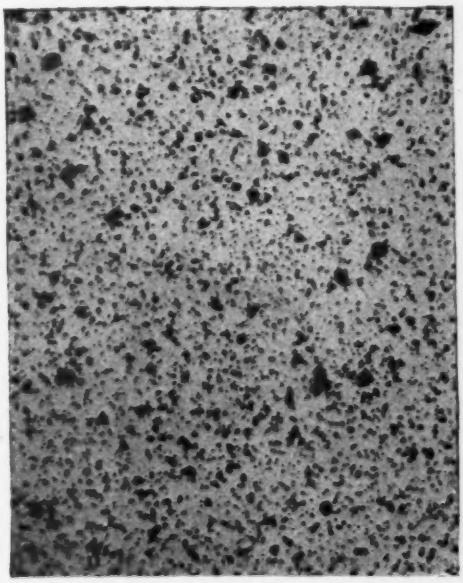


FIG. 92.—Same slide as shown in Fig. 89 but taken after disintegration was complete. × 200.

REPORT OF COMMITTEE D-4

ON

STANDARD TESTS FOR ROAD MATERIALS.

Committee D-4 recommends for adoption the following definitions of terms, with the understanding that they are intended to apply to materials of interest in road and paving work.

Asphalts.—Solid or semi-solid native bitumens, solid or semi-solid bitumens obtained by refining petroleum, or solid or semi-solid bitumens which are combinations of the bitumens mentioned with petroleums or derivatives thereof, which melt upon the application of heat and which consist of a mixture of hydrocarbons and their derivatives of complex structure, largely cyclic and bridge compounds.

Asphaltenes.—The components of the bitumen in petroleums, petroleum products, malthas, asphalt cements and solid native bitumens, which are soluble in carbon disulphide but insoluble in paraffin naphthas.

Blown Petroleums.—Semi-solid or solid products produced primarily by the action of air upon originally fluid native bitumens which are heated during the blowing process.

Carbenes.—The components of the bitumen in petroleums, petroleum products, malthas, asphalt cements and solid native bitumens, which are soluble in carbon disulphide but insoluble in carbon tetrachloride.

Cut-back Products.—Petroleum or tar residuums which have been fluxed with distillates.

Tars.—Bitumens which yield pitches upon fractional distillation and which are produced as distillates by the destructive distillation of bitumens, pyrobitumens or organic materials.

Coal Tar.—The mixture of hydrocarbon distillates, mostly unsaturated ring compounds, produced in the destructive distillation of coal.

Coke-oven Tar.—Coal tar produced in by-product coke ovens in the manufacture of coke from bituminous coal.

Dehydrated Tars.—Tars from which all water has been removed.

Gas-house Coal Tar.—Coal tar produced in gas-house retorts in the manufacture of illuminating gas from bituminous coal.

Oil-gas Tars.—Tars produced by cracking oil vapors at high temperatures in the manufacture of oil gas.

Pitches.—Solid residues produced in the evaporation or distillation of bitumens, the term being usually applied to residues obtained from tars.

Refined Tar.—Tar freed from water by evaporation or distillation which is continued until the residue is of desired consistency; or a product produced by fluxing tar residuum with tar distillate.

Water-gas Tars.—Tars produced by cracking oil vapors at high temperatures in the manufacture of carburetted water-gas.

Respectfully submitted on behalf of the committee,

L. W. PAGE,
Chairman.

PRÉVOST HUBBARD,
Secretary.

[NOTE.—According to the regulations governing the adoption of proposed standard definitions, the definitions proposed in this report are printed in the Proceedings, subject to action at the next annual meeting.—ED.]

MINORITY REPORT.

The undersigned members of Committee D-4, not being in sympathy with the report submitted to the Society by the majority of the committee in continuation of its attempts to define certain terms used in connection with highway construction, beg leave to submit the following minority report.

A majority of the committee reported at the last annual meeting of the Society, five definitions which were received and adopted by letter ballot on August 5, 1912. At the same meeting one of us presented a minority report in regard to these definitions which will be found on page 75 of the Proceedings for 1912, wherein it was stated that the definitions were, in his opinion, unsatisfactory both in matter and form, and in one instance at least, contrary to the etymological significance of the word defined, namely, that of bitumen, which was so worded as to include coal and other tars as bitumen. This definition plainly appealed to the majority of the members of the committee, and was approved by a large majority of the very small number of members of the Society voting upon its adoption by letter ballot, 78 yeas as compared with 6 nays, without having the minority report before them. The definitions having been submitted to the Society for ballot in that way, the author of the minority report brought the matter to the attention of the Executive Committee of the Society, and to one or two other members, with the result that the method of conducting the ballot was brought up at a subsequent meeting of the Executive Committee, and action was taken as shown by the following excerpt from the minutes:

"The Secretary was instructed to notify Mr. L. W. Page, the Chairman of Committee D-4 on Standard Tests for Road Materials, and also Mr. Clifford Richardson, a member of that committee, that it was the desire of the Executive Committee to have the Standard Definitions in question presented at the next annual meeting of the Society for further consideration. It was also agreed that at that time a recommendation should be offered on behalf of the Executive Committee that no action shall be taken relative to the adoption of proposed Standard Definitions until the meeting following

the publication of such proposed definitions in the Proceedings of the Society."

It was stated, however, that this action was taken without regard to the technical merits of the definitions objected to in the minority report, but rather with a view of reaching a solution that would be at once fair in its bearing on the present question and duly conservative in relation to such matters in the future.

In connection with this ballot, one of the leading engineering journals of this country, the *Engineering Record*, in an editorial on August 3, 1912, referring to attempts at standardization in the United States, stated:

"Without wishing to detract in any way from the value of this work, there have been occasional recent evidences that the thoroughness of the Germans is not being duplicated here in connection with all of the committee work, and particularly in its scrutiny by the men to whom it is submitted for approval. There is a tendency to accept blindly anything recommended by a committee, which is dangerous. It takes courage for an engineer to make a minority report, and he is inclined to stretch his professional conscience and affix his signature to a majority report which he considers defective to a greater or less degree. Yet in these minority reports lies the sole safeguard against too hasty action, and, in matters of standardization, minority reports of committees ought to be encouraged, distributed with those of the majority and given the most careful consideration."

In a further attempt to determine how general the acceptation of such a definition of bitumen would be in other countries, the author of the minority report submitted it, together with the definitions adopted by the Society, to M. Paul le Gavrian, Associate Secretary, International Association of Permanent Road Congresses, in Paris, asking for his opinion in the matter. In reply he stated:

"I am of your opinion as regards the abuse of the word 'bitumen'. It should be used only to denote natural products and not the tars and their derivatives. I go even farther than you and wish that the term 'bitumen' might be reserved solely for materials containing natural bitumen."

In a "Note of the Executive Committee on an Experiment in the Terminology to be adopted for Binding Materials with a Hydrocarbon Base which are employed in Roads," appearing in No. 3, March, 1913, of the Bulletin of the Permanent International Association of Road Congresses, is proposed for adoption, at least provisionally, the following definition of bitumen:

"*Bitumen:* The term bitumen should apply exclusively to natural opaque blackish or dark brown hydrocarbons which are generally solid or slightly fluid and which contain a small quantity of volatile products, found in pockets or impregnated in the rock. Pure bitumen dissolves completely in bisulphide of carbon."

At the same time the committee called attention to the fact that such a well-known authority on bitumen as Dr. George Lunge, Professor at the Polytechnic School of Zurich, stated as reporter of a committee of one of the Congresses of the International Society for Testing Materials some years ago, that the replies which he had received were too few in number to allow any conclusion to be deduced therefrom as to definitions of bituminous materials.

It appears, therefore, that some of the definitions proposed by Committee D-4 and adopted by ballot of the Society, would not be accepted by French experts, and that such a distinguished person as Doctor Lunge hesitates to undertake an acceptable definition of bitumen. In England the same differences of opinion are in existence as in other countries as may be seen by the correspondence in regard to the proper definition of bitumen and asphalt which has appeared in the *Surveyor* during the past year. In consequence of this situation the undersigned do not believe that it is desirable, or will be creditable to the American Society, to take part in such a controversial subject at the present time.

On the other hand, several well-known authorities support the position of the Sub-Committee on Definitions of Committee D-4 which it takes in defining the tars as bitumen. The whole subject, it will be seen, is a highly controversial one.

As another illustration of an attempt to define an industrial term, the action of a committee of the International Association for Testing Materials which attempted to define "steel," may be cited. On finding at the last congress in New York that the subject was controversial, the committee withdrew its report and no attempt was made to have the Association approve any definitions of this word.

The only object to be attained by arriving at a uniform system of nomenclature and a generally recognized definition of

the meaning of certain terms is to secure uniformity, accuracy and convenience in their use, and that there shall be no confusion in the way in which they are employed by various writers, as is too often the case. The question arises as to whether anything but a waste of time will result in attempts which are partisan and contentious, and represent only the efforts of individuals or groups in different countries, to sustain the position which they have taken. It would seem to the undersigned that under such circumstances, it would be more satisfactory to abandon anything of this kind and to recognize that, there being unreconcilable differences in existence, every writer, before he employs the terms in question, should state frankly the sense in which he uses them.

In view of these facts it would seem that no definition can be of value unless it is unanimously accepted by every one using the term. If this is not the case, nothing will be gained and the matter will still remain controversial.

Committee D-4 is again recommending at this meeting a further series of definitions which, while perhaps not so controversial as that of bitumen presented last year, except in the case of the word "asphalt," are not generally acceptable. While we might submit other definitions, which might meet our individual approval more satisfactorily than those which have been proposed, they would be in no less degree controversial and, on this account, no attempt will be made to do so at present. This minority report is made mainly with a view of bringing to the attention of the Society the entire subject of definitions of industrial terms, and the methods of voting upon them, with the idea of instructing the members of the Society in general as to the present status of the subject, and with the hope that it will be given careful consideration by the Society at its annual meeting and by the members before voting to adopt any of the definitions that are proposed.

Respectfully submitted,

CLIFFORD RICHARDSON,
C. N. FORREST.

DISCUSSION.

Sub-Committee on Nomenclature.

SUB-COMMITTEE ON NOMENCLATURE, OF COMMITTEE D-4.—The Sub-Committee on Nomenclature of Bituminous Materials, in undertaking to frame definitions of terms used in paving and road construction, has endeavored to formulate the usage throughout the United States of the words defined. It has not sought to make any innovations or to change in any way what has already been generally accepted by the producers and users of bituminous materials. To the committee there seemed a great need of defining the terms in a simple manner, to obviate certain confusions which are arising, and to present in a concise manner the ideas which were widely accepted but somewhat hazily defined.

The definitions which the committee has presented can create no confusion, either in trade or literature, as they follow along paths already defined by numerous writers and authorities. The work of the committee in no way binds anyone to accept the definitions of the Society. Those who choose can in the future define terms in their own writings to suit themselves, but it is hoped by the committee that the definitions offered are so simple and convenient that they will be widely recognized and adopted.

A close analysis of the minority report develops two main points, neither of which refers to the proposed new definitions, but refer to those terms already adopted by the Society. Of these "bitumen" is singled out for special criticism.

It should be noted that a former Sub-Committee on Nomenclature, of which Mr. Richardson was chairman, was called upon to define this and other terms. After prolonged inactivity the committee was dissolved and the present one appointed because an earnest effort at *constructive work* was demanded by the main committee. The present sub-committee is composed of men who have had a wide acquaintance throughout the United States with engineers and chemists representing the producers of every kind of road material, and with the

engineers and chemists of the Federal Government and of many of the states and cities. **Sub-Committee on Nomenclature.**

The term "bitumen" was carefully considered before a meeting of Committee D-4, and the adoption of the definition was recommended, with Mr. Richardson and Mr. Forrest as the only dissenters. Committee D-4 presented its report to the whole Society at one of the sessions of a very full meeting in New York, at which the registered attendance was 231. That the members who voted for final adoption on letter ballot were those who felt themselves competent to vote on the matter is indicated by the voters being limited to 84.

The undersigned believe that the definition of "bitumen" which has been adopted is entirely warranted, both by etymology and by common usage. Mr. Richardson himself has already included under this term, oil-asphalts, asphalt residuums, and certain products produced artificially from native asphalts and petroleums by means of heat, with or without air agitation and accompanied by more or less cracking and resultant chemical changes. If he includes these, why should he exclude the products produced from petroleum oils in making carburetted water-gas, which are known as water-gas tars, and also products produced by the destructive distillation of organic materials, which contain a large proportion of constituents identical with those contained in water-gas tars?

The definition of "bitumen" already adopted by the Society is that used by German authorities on coal tar and asphalt, such as D. Holde and J. Marcusson ("Proposals for Definition of Bitumen," Proceedings, International Association for Testing Materials, Vol. 2, No. 2). It is also used by such English and American authorities as:

Allen: "Organic Analysis," Vol. 3, Fourth Edition, p. 198;

Dr. David T. Day: "Production of Asphalt, Related Bitumens, Bituminous Rock, Mineral Resources, 1911." Doctor Day has also said in conversation that the new definition would be of great help to him in his work;

Prévost Hubbard: "Bitumens and Their Essential Constituents for Road Construction," Office of Public Roads, Circular No. 93;

Sub-Committee on Nomenclature.

American Railway Engineering Association, Vol. 14, No. 154, February, 1913, p. 840;

American Civil Engineers' Pocket Book, Second Edition, p. 1353;

Fourth Report, Special Committee on Bituminous Materials for Road Construction, American Society of Civil Engineers, Proceedings, February, 1913, p. 175.

"Bitumen" is also used in the sense adopted by the Society in the specifications of such states as New York, Pennsylvania, Illinois, New Jersey, etc., and by many city authorities like George W. Tillson, New York (see "Street Pavements and Paving Materials," p. 43).

The list could be extended indefinitely, but enough references have been given to show that the definition already adopted by the Society is in accordance with American usage, and to a considerable extent with foreign usage.

In conclusion, the undersigned believe that the action of the committee was entirely justified; that the adoption of the definition of "bitumen" and the other definitions already adopted is a great step in advance; that the adoption of the new definitions proposed would reflect credit on the Society, and be of great use to American chemists and engineers; and that such adoption would greatly promote universal acceptance of the meaning of these terms.

(Signed) A. H. BLANCHARD,
H. B. PULLAR,
P. P. SHARPLES,
PRÉVOST HUBBARD (*Chairman*).

Mr. Day.

MR. D. T. DAY.—It is part of my duty in connection with the Bureau of Geological Survey to prepare an annual report on the production of asphalt in the United States. When I undertook this work about three years ago, I found that the natural asphalt material taken out of the earth as solid asphalt, in Utah and elsewhere, was a minority of the material used in the asphalt industries. That proved an embarrassment which we solved by including as asphalt everything that was *used* as asphalt. The proportion of oil asphalt has increased very

rapidly. Three-fourths of all the asphalt that we use in the United States is obtained from asphaltic oils more or less treated, to make a material which is suitable as asphalt. Since the Survey is obliged to include such products as asphalt and bitumen, it is a great gratification to obtain the excellent definitions of these products which have been proposed by Committee D-4 of this Society. The chief embarrassment in this regard arose from the fact that there is an unbroken series of materials, starting with comparatively thin asphaltic oils and extending to thick asphaltic oils or really asphalt, whichever way you choose to call it, requiring practically no preparation before serving as road binder. Such asphalts we find in Utah, and they are practically identical with what is gotten by boiling off light products from asphaltic oils. In other words, Nature has boiled this off in some cases and man in others, and while the results differ slightly on account of the rapidity of reaction in one case and not in the other, the results and the process are very much the same. Mr. Day.

We know perfectly well the tenacity of the binding material which holds other elements together in road construction, and in our definitions it will aid us if we bind ourselves together in making a definition here which will represent actual conditions in America.

REPORT OF COMMITTEE D-5

ON

STANDARD SPECIFICATIONS FOR COAL.

Following the appointment of Committee D-5 in 1909, that committee was divided into several sub-committees of which each was charged to consider the subject of specifications as applied to a coal used for certain specific purposes, for example, coal used for steaming or power plant purposes, coal used for household or domestic purposes, coal used for the manufacture of gas, etc. After a considerable amount of work, the consensus of opinion of the members of the several sub-committees, except the sub-committee concerned with the specifications of coal for steaming or power plant purposes, is that our knowledge of the subject at the present time is inadequate to serve as a basis for a satisfactory specification.

Concerning the specification for coals to be used for steaming or power plant purposes, a much larger amount of work has been done than for any other branch of the subject; and important progress has been made, based upon actual experience as well as upon laboratory work, towards the preparation of a satisfactory specification for such coals. There are a few details, however, that have not been worked out to the satisfaction of a majority of the members of the committee, and especially is this true relative to the methods of sampling the coal to be purchased under such a specification.

The committee accordingly recommends that it be continued in the belief that by the end of another year it will be able to report a general specification for use in the purchase of steaming or power plant coals. Meanwhile, individual members of the committee will continue their inquiries and investigations concerning the possibility of specifications for coal to be purchased for other purposes.

Respectfully submitted on behalf of the committee,

J. A. HOLMES, *Chairman.*

G. S. POPE, *Secretary.*

REPORT OF COMMITTEE D-8

ON

WATERPROOFING MATERIALS.

Committee D-8, since its organization in 1905 has, as indicated by its yearly progress reports, through laboratory tests and experiments, together with examinations of work during construction and after completion, as well as the study of literature on the subject, sought to secure sufficient information to enable it to formulate definite methods for securing waterproof concrete structures. The work of the committee was complicated by reason of the facts that there seemed to be so little concordance between results of tests obtained under laboratory conditions and in the field and by the necessity of extending its investigations over a period of years in order to determine the permanency of the action noted.

The committee reports that while it has not been able to arrive at sufficiently definite conclusions to enable it to formulate specifications for the making of concrete structures waterproof or for materials to be used in such work, it has reached certain general conclusions which may be of assistance to the constructor in securing the desired result of impermeable concrete.

Early in the investigation, the work was found to sub-divide naturally into three branches, and the conclusions reached will be grouped in order under these sub-divisions, which are:

1. The determination of causes of the permeability of concrete as usually made from mixtures of Portland cement, sand and stone, or other coarse aggregate, in proportions of from 1 cement, 2 sand and 4 stone, to 1 cement, 3 sand and 6 stone, and the best methods of avoiding these causes;

2. The rendering of concrete more waterproof by adding to ordinary mixtures of cement, sand and stone, other substances which, either by their void-filling or repellent action, would tend to make the concrete less permeable;

3. The treatment of exposed surfaces after the concrete

or mortar has been put in place and hardened more or less, either by penetrative, void-filling or repellent liquids, making the concrete itself less permeable or by extraneous protective coatings, preventing water having access to the concrete.

Considering these several sub-divisions separately and in the order named, the committee finds:

1. *Causes of Permeability of Concrete.*—That in the laboratory and under test conditions using properly graded and sized coarse and fine aggregates, in mixtures ranging from 1 cement, 2 sand and 4 stone, to 1 cement, 3 sand and 6 stone, impermeable concrete can invariably be produced. That even with sand of poor granulometric composition, with mixtures as rich as 1 cement, 2 sand and 4 stone, permeable concrete is seldom, if ever, found and is a rare occurrence with mixtures of 1 cement, 3 sand and 6 stone. But the fact remains, nevertheless, that the reverse often obtains in actual construction, permeable concretes being encountered even with 1 cement, 2 sand and 4 stone mixtures and are of frequent occurrence where the quantity of the aggregate is increased. This we attribute to:

(*a*) Defective workmanship, resulting from improper proportioning, lack of thorough mixing, separation of the coarse aggregate from the fine aggregate and cement in transporting and placing the mixed concrete, lack of density through insufficient tamping or spading, and improper bonding of work joints, etc.;

(*b*) The use of imperfectly sized and graded aggregates;

(*c*) The use of excessive water, causing shrinkage cracks and formation of laitance seams;

(*d*) The lack of proper provision to take care of expansion and contraction, causing subsequent cracking.

Theoretically, none of these conditions should prevail on properly designed and supervised work, and are avoided in the laboratory and in the field, under test conditions, where speed of construction and cost are negligible items, instead of being governing features as they must be in actual construction. Properly graded sands and coarse aggregates are rarely, if ever, found in nature in sufficient quantities to be available for large construction, and the effect of poorly graded aggregates in producing permeable concrete is aggravated by poor and inefficient

field work. Even if we could afford the added expense of screening and re-mixing the aggregates so as to secure proper granulometric composition to give the density required to make untreated concretes impermeable, it is seemingly often a commercial impossibility on large construction to obtain workmanship even approximating that found in laboratory work.

2. *Addition of Foreign Substances to Cement or During Mixture.*—The committee finds that in consequence of the conditions outlined above, substances calculated to make the concrete more impermeable—either incorporated in the cement or added to the concrete during mixing—are often used. This has resulted in the development and placing on the market of numerous patented or proprietary waterproofing compounds, the composition of which is more or less of a trade secret.

While it has been impossible for the committee to test all of the special waterproofing compounds being placed on the market, it has investigated a sufficient number of these, as well as the use of certain very finely divided, naturally occurring or readily obtainable commercial mineral products, such as finely ground sand, colloidal clays, hydrated lime, etc., to form a general idea of the value of the different types. The committee finds:

(*a*) That the majority of patented and proprietary integral compounds tested have little or no immediate or permanent effect on the permeability of concrete and that some of these even have an injurious effect on the strength of mortar and concrete in which they are incorporated;

(*b*) That the permanent effect of such integral waterproofing additions, if dependent on the action of organic compounds, is very doubtful;

(*c*) That in view of their possible effect, not only upon the early strength, but also upon the durability of concrete after considerable periods, no integral waterproofing material should be used unless it has been subjected to long-time practical tests under proper observation to demonstrate its value, and unless its ingredients and the proportion in which they are present are known;

(*d*) That in general, more desirable results are obtainable from inert compounds acting mechanically, than from active

chemical compounds whose efficiency depends on change of form through chemical action after addition to the concrete;

(*e*) That void-filling substances are more to be relied upon than those whose value depends on repellent action;

(*f*) That, assuming average quality in sizing of the aggregates and reasonably good workmanship in the mixing and placing of the concretes, the addition of from 10 to 20 per cent of very finely divided void-filling mineral substances may be expected to result in the production of concrete which under ordinary conditions of exposure will be found impermeable, provided the work joints are properly bonded, and cracks do not develop on drying or through change in volume due to atmospheric changes, or by settlement.

3. *External Treatments.*—While external treatment of concrete would not be necessary if the concrete itself, either naturally or by the addition of waterproofing material, was impermeable to water, it has been found in practice that in large construction, no matter how carefully the concrete itself has been made, cracks are apt to develop, due to shrinkage in drying out, expansion and contraction under change of temperature, and moisture content and through settlement.

It is, therefore, often advisable on important construction to anticipate and provide for the possible occurrence of such cracks by external treatment with protective coatings. Such coating must be sufficiently elastic and cohesive to prevent the cracks extending through the coating itself. The application of merely penetrative void-filling liquid washes will not prevent the passage of water due to cracking of the concrete. The committee has, therefore, divided surface treatment into two heads:

(*a*) Penetrative void-filling liquid washes;

(*b*) Protective coatings, including all surface applications intended to prevent water coming in contact with the concrete.

While some penetrative washes may be efficient in rendering concrete waterproof for limited periods, their efficiency may decrease with time and it may be necessary to repeat such treatment. Some of these washes may be objectionable, due to discoloring the surface to which they are applied. The committee, therefore, believes that the first effort should be made

to secure a concrete that is impermeable in itself and that penetrative void-filling washes should only be resorted to as a corrective measure.

While protective extraneous bituminous or asphaltic coatings are unnecessary, so far as the major portion of the concrete surface is concerned, provided the concrete—either in itself or through the addition of integral compounds—is made impermeable, they are valuable as a protection where cracks develop in a structure. It is therefore recommended that a combination of inert void-filling substances and extraneous waterproofing be adopted in especially difficult or important work.

Considering the use of bituminous or asphaltic coatings, the committee finds:

(*a*) That such protective coatings are often subject to more or less deterioration with time, and may be attacked by injurious vapors or deleterious substances in solution in the water coming in contact with them;

(*b*) That the most effective method for applying such protection is either the setting of a course of impervious brick dipped in bituminous material into a solid bed of bituminous material, or the application of a sufficient number of layers of satisfactory membranous material cemented together with hot bitumen;

(*c*) That their durability and efficiency are very largely dependent on the care with which they are applied.

Such care refers particularly to proper cleaning and preparation of the concrete to insure as dry a surface as possible before application of the protective covering, the lapping of all joints of the membranous layers, and their thorough coating with the protective material. The use of this method of protection is further desirable because proper bituminous coverings offer resistance to stray electrical currents, the possible attack from which is referred to later.

So far, the committee has considered only concretes of the usual proportions, namely, those ranging from 1 cement, 2 sand and 4 stone, to 1 cement, 3 sand and 6 stone. It has been suggested that impermeable concretes could be assured by using mixtures considerably richer in cement. While such practice would probably result in an immediate impermeable

concrete, it is believed by many that the advantage is only temporary, as richer concretes are more subject to check cracking and are less constant in volume under changes of conditions of temperature, moisture, etc. Therefore, the use of more cement in mass-concrete would cause increased cracking, unless some means of controlling the expansion and contraction be discovered. With reinforced concretes the objection is not so great, as the tendency to cracking is more or less counteracted by the reinforcement.

It has also been suggested that the presence in the cement of a larger percentage of very fine flour might result in the production of a denser and more impermeable concrete, through the formation of a larger amount of colloidal gels.

Neither of these suggestions have been especially investigated by the committee. Both appeal to the committee, however, for the reason that they substitute active cementitious substances for the largely inactive void-filling materials previously recommended, thus increasing the strength of the concrete.

In conclusion, the committee would point out that no addition of waterproofing compounds or substances can be relied upon to completely counteract the effect of bad workmanship, and that the production of impermeable concrete can only be hoped for where there is determined insistence on good workmanship.

The production of impermeable concrete has assumed greater importance since the appointment of this committee, owing to the well-known injurious action of saline or alkaline waters and to the suggested possible effect of the moisture in concrete occasioning or aggravating electrical action from stray currents.

Originally, the question of waterproofing involved mainly the physical troubles resulting from water passing through concrete without any special consideration of its effect on its durability, other than a gradual leaching out of the cement. Recent developments suggest the possibility that owing to the increased conductivity of damp concrete to electrical currents, such currents, if present, may so affect damp concrete as to seriously lessen its integrity, and this possibility further emphasizes the importance of the recommendation that no waterproofing com-

pound of unknown chemical composition be added to concrete, as recent tests seem to show that the action of electrical currents is aggravated by the presence of certain solutions.

Respectfully submitted on behalf of the committee,

W. A. AIKEN,
Chairman.

CYRIL DE WYRALL,
Secretary.

NOTE.—Following the presentation of the report of Committee D-8, it was decided to refer certain proposed changes to the committee, with the understanding that if they were not unanimously adopted the report would be referred back to the committee. These changes, noted below, having been unanimously adopted by the committee, the report is printed above in its revised form.—ED.

Page 460, line 16: Insert "often" after "reverse."
Page 461, line 4: Insert "often" after "seemingly."
Page 461, line 6: Omit the following sentence: "It therefore seems that we can secure impermeable concrete most economically by adopting some special waterproofing treatment."
Page 461, line 9: Omit "the use of" before "substances."
Page 461, line 11: Substitute "are often used" for "has become general."
Page 461, line 24: Insert "immediate or" after "no."
Page 462, line 34: Substitute "some" for "many"; substitute "may be" for "are."
Page 462, line 35: Substitute "may" for "is apt to."
Page 463, line 10: Substitute "of inert void-filling substances" for "of the two methods, integral."

REPORT OF COMMITTEE D-11

ON

STANDARD SPECIFICATIONS FOR RUBBER PRODUCTS.

Committee D-11 was appointed in December, 1911, and the first meeting for the organization and selection of sub-committees was held in New York, at the Chemists' Club, on February 24, 1912.

Messrs. E. B. Tilt and E. A. Barrier were elected Chairman and Secretary respectively.

After some discussion of the present situation with reference to rubber products, the more important materials were enumerated, and sub-committees were decided upon with the chairmen as follows:

Sub-Committee I on Air Hose, E. B. Tilt, Chairman.
Sub-Committee II on Belting, S. P. Thacher, Chairman.
Sub-Committee III on Cold-Water Hose, E. A. Barrier, Chairman.
Sub-Committee IV on Floor Covering, D. A. Cutler, Chairman.
Sub-Committee V on Insulated Wire, C. D. Young, Chairman.
Sub-Committee VI on Packing and Gaskets, W. A. Derby, Chairman.[1]
Sub-Committee VII on Pump Valves, E. S. Land, Chairman.
Sub-Committee VIII on Steam Hose, J. B. Young, Chairman.

A second meeting was held at the Hotel Astor, New York, during the annual meeting of the Society in March, 1912, when there was a discussion regarding the committee work and the

[1] Owing to the lamented death of Mr. Derby, this sub-committee has been merged with that on pump valves, and the designations of Sub-Committees VII and VIII changed to VI and VII respectively.

outlining of the work to be accomplished. The membership of the committee was increased and the personnel of the sub-committees made known where selection had been made. A notice was also given on the floor, on the last day of the Society's meeting, of the creation of this committee and the scope of its work.

A third meeting of the committee was held in New York in the latter part of September, during the Third International Rubber Conference, at which there was further discussion as to the work of the sub-committees, the membership, and the material available for specifications. Since then, the sub-committees have been gathering data and making an effort to draw up specifications, the results of which are given herewith in brief.

Sub-Committee I on Air Hose.—No members are selected for air-brake hose on account of the fact that this subject is a live issue with the Master Car Builders' Association, which has a special committee on this work and which includes two members of Committee D-11. It was therefore decided to defer action until the Master Car Builders' Association had come to some decision. Pneumatic-tool hose will now be taken up.

Sub-Committee II on Belting.—Owing to change of residence and business of the chairman, this sub-committee was not organized, and no progress has been made. Mr. C. D. Young is now organizing the sub-committee.

Sub-Committee III on Cold-Water Hose.—Meetings of this sub-committee have been held, and specifications for rubber-lined fire hose have been submitted by the chairman to the members and general committee for their consideration, and will be submitted to the Society at the next annual meeting.

Sub-Committee IV on Floor Covering.—No organization of this sub-committee has been made, but this will be done immediately.

Sub-Committee V on Insulated Wire.—As this subject is receiving attention by Committee D-9 of our Society, as well as by other technical societies, it has been decided to await the result of the present investigations in hand before drawing up or endorsing specifications.

Sub-Committee VI on Packing, Gaskets and Pump Valves.—This sub-committee has completed some specifications, and it

will be in position to submit a number to the Society at the next annual meeting.

Sub-Committee VII on Steam Hose.—This sub-committee has been collecting data and considering present specifications, and will submit a specification at the next annual meeting.

The chairman and secretary of the committee were in attendance as representatives of the Society, at the International Rubber Conference held in New York in September, 1912, but the proceedings of the Conference have been so generally given in the technical journals that we do not consider that a separate report to the Society is required.

Respectfully submitted on behalf of the committee,

E. B. TILT,
Chairman.

E. A. BARRIER,
Secretary.

REPORT OF COMMITTEE E-1

ON

STANDARD METHODS OF TESTING.

The work performed by Committee E-1 during the past year has been confined to that of its Sub-Committee on Methods of Chemical Tests, consisting of Mr. Robert Job, Chairman, and Messrs. W. A. Bostwick, Henry Fay, Henry M. Howe, Henry P. Talbot, G. D. Chamberlain, H. E. Diller and O. Linder.

This sub-committee was organized to develop standard methods for the analysis of steel, and the work was placed in the charge of Messrs. Fay and Chamberlain. These gentlemen have recently reported their recommendations to the chairman of the sub-committee, but the work will now be discontinued owing to the appointment of a sub-committee by Committee A-1, on Standard Specifications for Steel, for the same purpose; and in order to avoid confusion and duplication of work, Committee E-1 has voted to refer the methods as proposed by Messrs. Fay and Chamberlain to the chairman of the sub-committee of Committee A-1 for its information.

Respectfully submitted on behalf of the committee,

GAETANO LANZA,
Chairman.

REPORT OF COMMITTEE E-5

ON

REGULATIONS GOVERNING THE FORM BUT NOT THE SUBSTANCE OF SPECIFICATIONS.

By authorization of the Executive Committee the responsibility for the Regulations Governing Technical Committees has been vested in Committee E-5, which includes the chairmen of all committees dealing with specifications, with the understanding (1) that proposed changes in these Regulations originating with Committee E-5 shall be subject to approval by the Executive Committee of the Society; and (2) that the Executive Committee of the Society will make no changes in these Regulations without having first referred them to Committee E-5.

In pursuance of this authorization the following changes have been made in the Regulations Governing Technical Committees, which appear in Volume XII of the Proceedings, pages 531–534:

1. The insertion of the following new section after the present section on "Specifications":

> "*Standard Definitions.*—The procedure governing action on proposed new standard definitions or the proposed amendment of existing standard definitions shall be in precise conformity with that above defined in relation to "Specifications," except that such new or amended definitions shall not be referred to letter ballot of the Society prior to the annual meeting following their publication in the Proceedings of the Society."

2. The addition of the following sentence to the section on "Discharge of Committees":

> "A technical committee which fails to present a report at three successive annual meetings of the Society will be required to show cause, in a written communication to the Executive Committee, why it should not be discharged."

The Committee has also revised and extended the list of abbreviations, etc., in the Regulations Governing the Form but not the Substance of Specifications, Standard Methods of Tests, etc. (See Year-Book for 1912, pages 105–113.) The changes involved are not considered of sufficient importance, however, to be mentioned here in detail, but will appear in the revised Regulations in the Year-Book of the Society for 1913.

Respectfully submitted on behalf of the committee,

EDGAR MARBURG,
Chairman.

[NOTE.—For action taken in connection with this report, see pp. 15–16.—ED.]

REPORT OF COMMITTEE E-6

ON

PAPERS.

In announcing the appointment of Committee E-6 on Papers, the Executive Committee defined the authority and duties of the committee in the following terms:

> 1. Authority for the acceptance of papers shall be vested in a Committee on Papers broadly representative of the principal interests in the Society, whose membership shall be subject to enlargement under the Regulations Governing Technical Committees. This committee will also cooperate in an advisory capacity with the Secretary in the preparation of the technical program for the meetings. The Secretary of the Society shall be the chairman of the committee.
>
> 2. This committee shall be authorized to draw up its own regulations, which shall be subject to the approval of the Executive Committee. Any modifications in these regulations which may be proposed from time to time shall be similarly subject to the approval of the Executive Committee.

The committee has given careful consideration to the practices of other leading national societies in matters affecting the acceptance and publication of papers and discussions, and has drawn up the regulations which appear in the appendix to this report. As already announced through a circular notice to the membership of the Society at large, these regulations have been approved by the Executive Committee, with the understanding that they shall be regarded as of a tentative nature and subject to modification in the light of experience. The members of the Society are invited to discuss and criticise these regulations freely. The sole aim of the committee is that the publications of the Society shall be placed on the highest possible plane, and any suggestions to that end will be gratefully received. All such communications should be addressed

to the Secretary of the Society, as chairman *ex-officio* of the committee.

The committee has also formulated certain administrative regulations for its own guidance, which are designed, on the one hand, to safeguard the interests of the Society as well as those of intending contributors to the Proceedings, and on the other, to avoid vexatious delays and serious dissatisfaction that would be apt to result from unnecessary "red tape."

The committee has spared no efforts to make the new regulations operative at once in relation to the material presented at this meeting, with the following results: Of the 23 committee reports and 37 papers included in the program for the annual meeting, 19 committee reports and 33 papers, totaling some 700 printed pages, have been put in print in advance of the meeting, and with relatively few exceptions this matter has been distributed among the membership of the Society from two to four weeks before the date of the meeting. This leaves only 8 out of a total of 60 contributions unaccounted for. In these exceptional instances the authors found it impracticable to furnish their manuscripts sufficiently far in advance of the meeting to admit of preprinting. Such exceptions are always to be expected unless the regulations are made more rigid than the committee deems advisable. The committee has used its best efforts to minimize their number and with the experience gained this year it is hoped that even better results will be attainable in the future.

Respectfully submitted on behalf of the committee,

EDGAR MARBURG,
Chairman.

[NOTE.—For action taken in connection with this report, see p. 16.—ED.]

APPENDIX.

REGULATIONS GOVERNING PAPERS, COMMITTEE REPORTS AND DISCUSSIONS.

Authority of Committee.—Committee E-6 on Papers has been given full authority by the Executive Committee in all matters affecting the acceptance, rejection, editing and publication of papers and discussions.

Preprinting of Papers and Committee Reports.—The Committee on Papers proposes to use its best endeavors to put the papers and committee reports to be presented at annual meetings in type for advance circulation. To render this practicable, the manuscripts should be sent to the Secretary at least two months in advance of the meeting at which they are to be presented. The committee will then endeavor to issue preprints to the membership at large one month in advance of the meeting. It is manifest, however, that if all papers forming part of a comprehensive program should be received only two months in advance of the meeting, it would not be practicable to have them all put in type in a single month. ***Authors and chairmen of committees are accordingly requested to furnish their manuscripts as far in advance of the meeting as possible.***

In general, the sequence in which the papers are received will determine the sequence in which they will be printed. Manuscripts received too late for printing and advance circulation will be put in type, in so far as practicable, with a view of having them available in printed form at the meeting.

The committee reserves the right to reject papers received too late for advance printing, although exceptions will be authorized at the discretion of the committee.

Specifications.—Attention is called to the following excerpt from the Regulations Governing Technical Committees:

> "Any recommendation affecting specifications must be transmitted to the Secretary of the Society at least eight weeks in advance of the date of the annual meeting,

and copies of these recommendations, in printed form, must be mailed by the Secretary to every member of the Society not less than four weeks before the annual meeting so that members may come to the meeting prepared to discuss such recommendations, and that members not intending to be present at the meeting may contribute discussions by letter."

Editing of Papers and Discussions.—The Committee on Papers will edit and revise papers for publication. If such editing and revision is not acceptable to the author, the committee will endeavor to meet the wishes of the author as far as possible, but if a revision acceptable to both the committee and the author cannot be reached, the papers shall not be presented or published.

The above provisions are applicable also to written or verbal discussion.

In the editing of matter for the publications of the Society, the requirements as to "typography, standard terms, abbreviations, spelling, etc.," contained in the Regulations Governing the Form but not the Substance of Specifications, will be adhered to. It is recommended that authors assist the Committee on Papers by following these requirements in the preparation of their manuscripts.

Rejection of Papers.—The rejection of papers will be determined chiefly on the following grounds:

(*a*) That the subject matter does not fall within the field of the Society's activities.
(*b*) That the contents are of an advertising character.
(*c*) That the author controverts well-established facts.
(*d*) That the subject-matter is essentially of a speculative nature.
(*e*) That the subject-matter is not new.
(*f*) That the treatment is seriously defective as to literary form and structure, continuity of thought, clarity of expression, etc.

The committee reserves the right, however, to reject papers on grounds other than those above stated; for example, a paper

in which sweeping generalizations are premised on manifestly inadequate data; a paper embodying trade secrets, for example, one descriptive of the properties of a product whose composition or manufacture are not disclosed; or, again, a paper containing the results of tests calculated to do injury to commercial interests, unless representatives of those interests witnessed the tests, or are given the opportunity of preparing discussions for presentation concurrently with the paper.

Outside Publication.—No paper, committee report, or written discussion shall be released for publication in the daily or technical press in advance of its presentation, except by authority of the Committee on Papers; nor after its presentation, unless it has previously been edited by the committee or the committee agrees to release it without editing.

No person shall receive monetary compensation from reprinting any paper or discussion presented before the Society, without previous authorization from the committee, and in all reprints credit must be given to the Society.

OXYGEN IN IRON AND STEEL: VALUE OF EXISTING METHODS FOR ITS DETERMINATION.

By W. R. Fleming.

It is a lamentable fact that we have no trustworthy method for the determination of oxygen in iron and steel. At the present time the Ledebur method is the only one used by chemists to any extent. In the writer's opinion, this method is little better than no method at all, for it is both inaccurate and misleading. In the cases of steel and wrought iron the method is practically worthless, for most of the oxygen in steel is in combination with manganese, silicon, chromium, aluminum, etc., and much of the oxygen in wrought iron is in the silicates and phosphates of the cinder. It is well known that oxygen united with these elements is not obtained by the Ledebur method. Yet in spite of this some chemists waste their valuable time attempting to determine oxygen by the Ledebur method.

Several companies are now manufacturing ferrous metals in open-hearth furnaces that approach closely to pure iron. These metals are practically free from manganese, silicon and other elements whose oxides will not decompose in hydrogen. Consequently the oxygen in these metals is practically all in combination with iron, and since all oxides of iron give up their oxygen when ignited in hydrogen it follows that here the Ledebur method must have some value. Although in this special class of ferrous metals the Ledebur method gives results nearest to the truth, at the same time I wish to show in this paper that even here the method has a very limited value.

A method outlined by Walker and Patrick at the last Congress of Applied Chemistry may eventually prove a reliable means of determining oxygen in steel. By this method the total oxygen in the steel is obtained as carbon monoxide by heating to a high temperature, in the presence of carbon, in a vacuum. The great objection to this method is the extremely large blank that has to be deducted. However, the method is undoubtedly far superior to the Ledebur method and it is to be hoped that the originators of this unique method will bring it to a degree

of accuracy which will enable us to class it with the exact methods we have for carbon, manganese, etc.

In republishing the Ledebur method a few years ago, Dr. A. S. Cushman deprecated the fact that American chemists had failed to give sufficient attention to the determination of oxygen in steel, and that text books on steel analysis had failed to include a method for it. This attitude of American chemists is not surprising, for they undoubtedly realized that there was no method sufficiently accurate to justify a description in text books, not even to justify the wasting of valuable time in the laboratory. The fact that the Ledebur method is not described in any work on analytical chemistry, except that of Ledebur himself, surely has some significance, especially when we consider that Ledebur published the method over thirty years ago. If it had any great value it surely would have found its way into some of our standard analytical books.

For the purpose of this paper I will take for granted that when analyzing ferrous metals free from difficultly decomposed oxides, the Ledebur method obtains all of the oxygen, provided the sample is sufficiently divided. I would remind you, however, that in some instances considerable aluminum is used as a deoxidizing agent in place of ferromanganese, and in these cases there is undoubtedly some aluminum oxide in the metal, which, of course, would be untouched by ignition in hydrogen.

It is a surprising fact that all writers who have described methods for the determination of oxygen have failed to discuss the most important feature, namely, the taking of the sample. It is absurd to waste time determining an element unless we know that the drillings we are analyzing are representative of the entire mass. We have very little trouble securing representative samples of drillings for the determination of carbon, manganese, etc., and most chemists seem to take for granted that representative samples for oxygen can be secured in the same way. This is not true. The carbides, sulphides and phosphides of iron and manganese exist in a state of solution and are fairly uniform in well-made steel. The oxides of iron do not exist in this intimate relation with the metallic body; they are mere mechanical impurities and arrange themselves throughout the metal according to mechanical laws. During slow

cooling of liquid metal in ingot molds, the oxides travel slowly inward and upward, leaving the solidified ingot irregular in oxygen. On this account it is difficult, if not almost impossible, to get drillings for analysis which will represent the true oxygen content of the entire mass. Certainly one or two pieces taken at random from a shipment will give the purchaser no idea of the true percentage of oxygen.

I have examined a great number of ingots of nearly pure ferrous metal and in every case I have found the oxygen very irregularly distributed, the outside invariably being lower in oxygen than the center, and the lower portions of the ingots

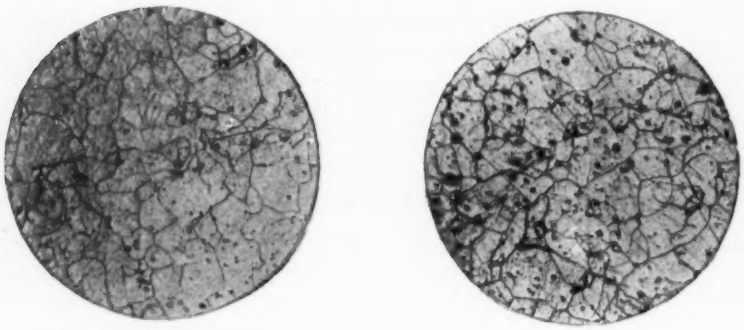
TABLE I.—PERCENTAGE OF OXYGEN.

Bar No.	First Eighth Inch in Bar, "Outside."	Fourth Eighth Inch in Bar, "Center."
1 (near top)	0.047	0.098
2	0.032	0.107
3	0.052	0.088
4	0.055	0.096
5	0.023	0.074
6	0.047	0.090
7	0.022	0.041
8 (near bottom)	0.036	0.062

invariably containing less than the upper portions. It did not matter whether the metal contained little or much oxygen; the variation existed just the same.

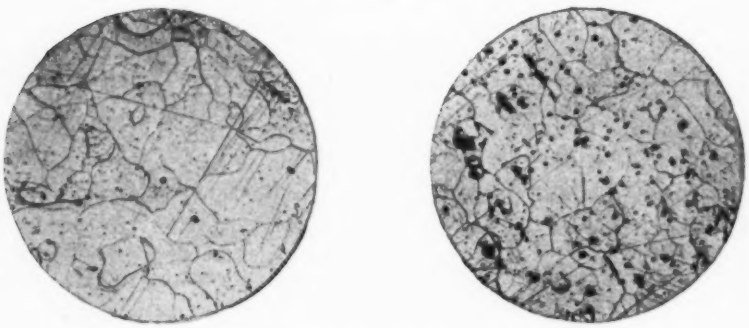
Ingots weighing over 5000 lb. were rolled out into sheet bars 1 in. thick and 8 in. wide. After cutting off a good "crop" at the upper end, Sample No. 1 was cut, then samples cut at eight equal distances from top to bottom. Two oxygen determinations were made on each sample by the Ledebur method, one from the drillings cut from the first eighth inch below the surface, and one from drillings cut from the center. The results from an ingot containing considerable oxygen are given in Table I.

Figs. 1 to 8 show microphotographs of sections corresponding to the locations from which the above drillings were taken. Table I, together with the microphotographs, shows the great difficulty in obtaining representative drillings for oxygen determination.



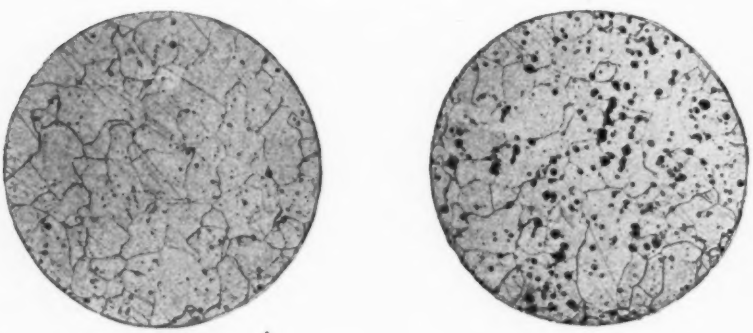
(*a*) First Eighth Inch. (*b*) Center.

FIG. 1.—Bar No. 1.



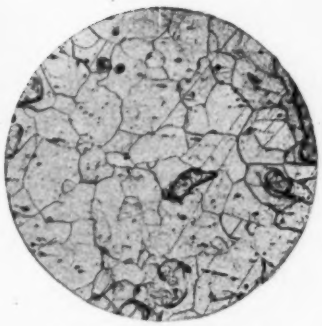
(*a*) First Eighth Inch. (*b*) Center.

FIG. 2.—Bar No. 2.

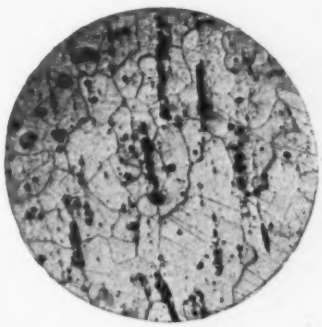


(*a*) First Eighth Inch. (*b*) Center.

FIG. 3.—Bar No. 3.

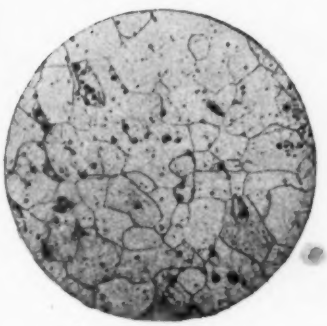


(*a*) First Eighth Inch.

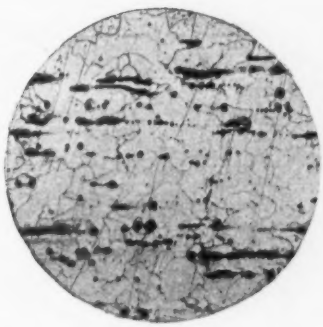


(*b*) Cente·

FIG. 4.—Bar No. 4.

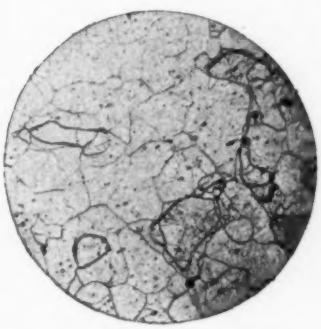


(*a*) First Eighth Inch.

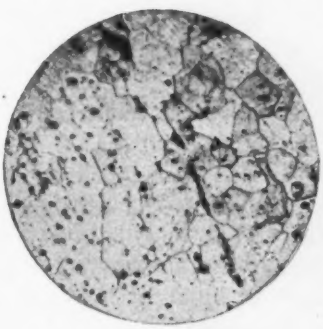


(*b*) Center.

FIG. 5.—Bar No. 5.



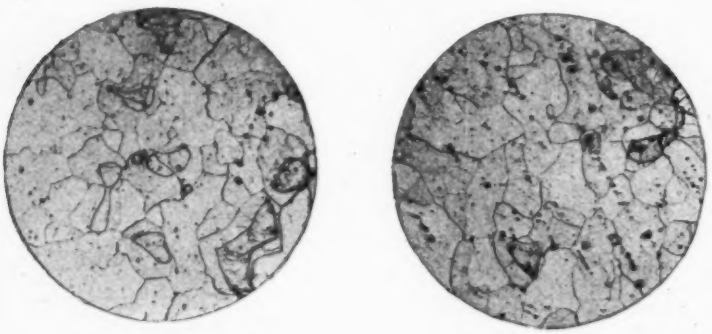
(*a*) First Eighth Inch.



(*b*) Center.

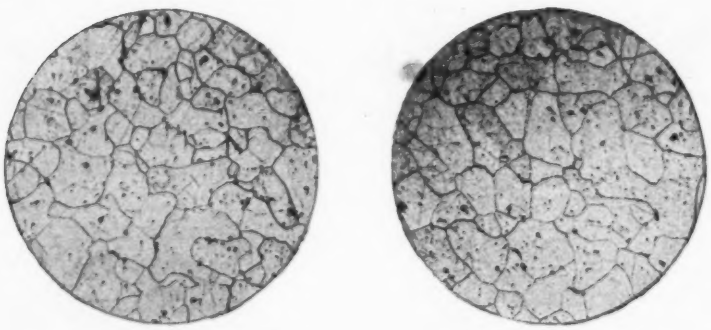
FIG. 6.—Bar No. 6.

I am convinced that the analyses of one or two pieces cannot be of any value. Furthermore, I am convinced that unless the analyst knows the location of the piece, whether it came from the top, middle, or bottom of the ingot,—in other words. unless he knows the history of the sample,—the result he obtains



(*a*) First Eighth Inch. (*b*) Center.

FIG. 7.—Bar No. 7.



(*a*) First Eighth Inch. (*b*) Center.

FIG. 8.—Bar No. 8.

will be of little real value. From this it follows that the manufacturer is the only one that can get a true (approximately true) idea of the amount of oxygen contained in all the pieces rolled from an ingot, or from a whole heat.

Great importance is being attached by some companies to the amount of oxygen contained in sheet metal, it being

claimed that this element is an accelerator of corrosion. In support of this view, meaningless laboratory tests and vague theories are advanced. As a matter of fact there is absolutely no evidence which even indicates that oxygen is an accelerator of corrosion. On the contrary we have an abundance of testimony pointing in the opposite direction. We know that wrought iron resists corrosion much better than steel and we know that most wrought iron is polluted with oxygen. We know that the "piles" are made of muck bars covered with thick coatings of iron oxide and we know that this iron oxide is present in the finished sheet. The very method of manufacture itself produces metal high in oxygen. This evidence, produced by years of practical experience, is infinitely more convincing than the most ingenious laboratory test or the most subtle theory.

While I do not defend wrought iron and while I believe that metal can be made in the open-hearth furnace which will be even more rust-resisting than wrought iron, at the same time I believe we are unfair when we compare percentages of oxygen in the two metals and use the high percentage in wrought iron to lead prospective buyers away from it. It is my opinion that, if the truth were known, oxygen retards rather than accelerates corrosion.

REMARKS ON LEDEBUR METHOD.

Dr. A. S. Cushman published the Ledebur method in the Journal of Industrial and Chemical Engineering, Vol. 3, p. 372. He used a gas blast furnace which simultaneously heated the preheating and ignition tubes. While there is no objection to this if the hydrogen is perfectly free from oxygen, there is a decided objection to it if the hydrogen contains oxygen. In this case all of the oxygen that is in the apparatus, at the time a certain temperature is reached, between the preheating tube and the weighing apparatus, is weighed and counted as oxygen in the steel. It is true that the running of a blank may correct this error to some extent, but there is no way of knowing the exact error that is introduced in this way with every determination. The best, and by far the safest, arrangement is to employ a preheating furnace, and the furnace best for this purpose is an electric resistance furnace. This can be made by any-

one with little work and almost no expense. A gas furnace for blast is best for ignition of the samples.

The train used by the writer is shown in Fig. 9. The hydrogen is generated by stick zinc and dilute hydrochloric acid. By placing 15 lb. of stick zinc in the generator it need not be disturbed for over one hundred determinations. The great advantage of this is apparent. R and R_1 provide constant pressure and improve the apparatus 100 per cent over that with a Kipp alone.

The weighing apparatus is weighed filled with hydrogen. Aspirating with air before weighing is not only a waste of time but introduces more error than it corrects. If the weighing tube has perfectly ground stoppers it should be weighed filled

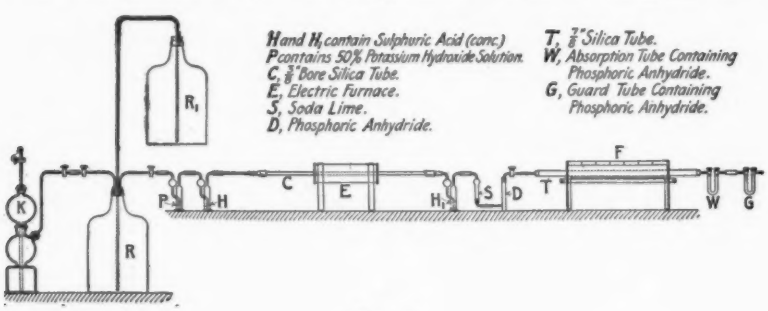


FIG. 9.

with hydrogen; if not, it is best to weigh filled with air. To test the tube fill it with hydrogen and weigh against a tare. Weigh again at equal intervals for several hours. If it gains in weight it should be used for some other purpose. In ordering these tubes perfectly ground joints should be insisted upon.

If the apparatus is in good order constant blanks of 0.0015 gram will be obtained, whether the atmosphere be hot or cold, moist or dry.

R. H. McMillen has recently published the Ledebur method claiming the following features as improvements: use of electric resistance furnace for ignition of the sample; use of porcelain boats; use of pyrogallic acid in the train; weighing of the absorption tube filled with hydrogen. Dr. Cushman criticised the article on the ground that no contribution had been made to the older method. The stand taken by Cushman is undoubt-

edly taken by all chemists who have had experience with the Ledebur method, for it is difficult to see wherein McMillen has made the slightest improvement in the method. As Cushman has said, the electric furnace is not adapted to this method because it requires too much time heating and cooling. The first train set up by the writer, over five years ago, contained the two improvements claimed by McMillen, namely, two resistance furnaces and pyrogallic acid. The second electric furnace, for heating the sample, was abandoned a few days later for reasons pointed out by Cushman. A short time afterward I learned that the use of pyro was unnecessary and abandoned that also.

As to the other improvements claimed by McMillen, the use of porcelain boats and weighing of the tube filled with hydrogen, little need be said. Any chemist, in his first experiments with the method, would naturally use porcelain boats. Cushman criticises the use of porcelain on the ground that it absorbs moisture. This criticism is slightly overdrawn, for, as McMillen has said, with little precaution no error will be introduced in this way. The most important criticism made by Cushman was on the practice of weighing the absorption tube filled with hydrogen. He attacks this practice on the ground that hydrogen diffuses through "air-tight" stoppers. On this point I beg to disagree with Dr. Cushman. I have been weighing absorption tubes filled with hydrogen for over five years and wish to say emphatically that hydrogen does not diffuse through the stoppers if they are ground as they should be. If the chemist will take the time to test the U-tubes to satisfy himself that the stoppers are well ground he need have no fear of hydrogen diffusing through the stoppers.

The following experiment on this point may be of interest to some: A U-tube, loaded with glass wool and phosphoric acid, was filled with hydrogen and placed in an ordinary desiccator. It was weighed at intervals for five months and at the end of five months it weighed exactly the same as on the day it was filled with hydrogen.

In his article McMillen called attention to the well-known fact that the Ledebur method obtains only that oxygen which is combined with iron, and that it fails to decompose the oxides

of manganese, silicon, etc. Replying to this, Dr. Cushman states that it is not necessary to know the amount of oxygen combined with manganese, silicon, etc., because the amount of iron oxide measures the extent to which the metal has been over-oxidized in the furnace. It is difficult for the writer to understand the point of view taken by Dr. Cushman. Practically all basic steel, at the time of tapping, contains from 0.15 to 0.25 per cent of manganese. Is it Dr. Cushman's opinion that none of this manganese is combined with oxygen? From our practical knowledge of the affinity of iron and manganese for oxygen we must assume that the small amount of oxygen usually found in steel at the time of tapping is in combination with manganese, or at least we must assume that manganese has its share of the oxygen. For the sake of argument we will assume that all of the oxygen in the metal at the time of tapping is in combination with iron, and that the metal contains 0.10 per cent of oxygen. To deoxidize this highly over-oxidized metal, ferromanganese and ferrosilicon are added in the ladle. If enough of these deoxidizing materials has been added, and if they accomplish the purpose for which they were added, then the metal will be free from iron oxide and will contain a certain amount of manganese and silicon oxides which could not find their way to the slag. In this ideal case would not the amount of manganese oxide and silica bear some relation to the amount of oxidation that had taken place in the furnace?

In the manufacture of pure open-hearth iron the metal, at a certain stage in the process, contains from 0.06 to 0.10 per cent of oxygen. If tapped at this stage, without the addition of any deoxidizing agent, no difficulty will be experienced in rolling it. If, however, ferromanganese and ferrosilicon are added (say 200 lb. of each) in the ladle the metal will crumble to pieces in the rolls. This is due to the fact that the manganese and silicon rob the iron of its oxygen and in some mysterious way render the metal extremely red-short. If these oxides had found their way to the slag, the metal, in all probability, would have been improved. This is mentioned to show that the oxides of manganese and silicon, formed on the addition of ferromanganese and ferrosilicon to over-oxidized metal, do not find their way to the slag but remain to a great extent in the metal.

DISCUSSION.

Mr. A. S. Cushman.

MR. A. S. CUSHMAN.—I have been interested in the Ledebur method for the determination of oxygen in iron and steel, and I published the Ledebur method in this country with some slight modifications in the effort to bring it up to date. I was a student under Professor Ledebur and used to have the privilege of hearing him discourse on the subject of oxygen in steel and on the general subject of deoxidation. I am free to confess that the determination of oxygen in steel by the Ledebur method is a difficult method in the hands of the ordinary commercial laboratory, for we must realize that we are dealing at best with extremely minute quantities. The upper range has just been stated here, we will say 0.12 per cent. The usual range of oxygen content by the Ledebur method is from 0.02 to 0.08 per cent. That is to say, we are dealing with the determination of a few hundredths of one per cent of oxygen in the metal. Now you will readily see that in such a determination a great deal must depend upon the way the sample is prepared, and cared for. The slightest bit of superficial rust on the turnings which have been taken, will lead to high results. Again, much depends upon the man and machine that cut the samples, for they may easily be a little burned in machining without oil.

It is true that the Ledebur method does not determine total oxygen. Oxides of manganese, aluminum and silicon, and oxygen in slag, are not reducible in hydrogen. If one wishes to determine total oxygen in steel, this method will not answer. But if one wishes to know how much oxygen is combined with iron in contradistinction to oxygen that may be bound up with manganese or slag, the Ledebur method is the only one that will give the desired information. If a method ever is discovered that will distinguish the oxygen combined with manganese and slag from that combined with iron, it will be valuable; but I fail to see that the determination of total oxygen without respect to the elements with which it is combined, gives any information worth having.

Mr. Cushman. As to the point raised by the speaker in regard to weighing the absorption tube full of hydrogen, I can only say that I was taught at college to replace other gases with dry air before attempting to make very accurate weighing. It only takes a few minutes, and when we are concerned with the estimation of very minute quantities of oxygen the precaution is certainly called for.

Mr. Bassett. MR. W. H. BASSETT.—The photographs shown are extremely interesting. Such spots are always to be seen in copper, or in alloys of copper and nickel which contain oxygen, but are never present in deoxidized copper or alloys. It therefore seems fair to conclude that they are due to oxygen. The photographs so closely resemble those of copper-nickel alloys containing oxygen that, if they had been presented as such, no one could have had reason to express doubt.

EFFECT OF SIZE OF SECTION ON PHYSICAL PROPERTIES DEVELOPED BY HEAT TREATMENT.

By J. H. Nead.

In these days of the wide-spread use of heat-treated alloy steels for the highly stressed and vital parts of automobiles and other types of machinery, it is necessary that the designer, in order to properly take advantage of these materials and to properly proportion the separate parts of the design, shall know what physical properties may be expected of these different materials when they have been subjected to varying heat-treating conditions.

Tables and lists of the physical properties of all of the commercial alloy steels at present on the market may be readily obtained gratuitously from the makers of these materials, and these tables of physical properties will in general contain the following items: elastic limit in pounds per square inch, maximum tensile strength in pounds per square inch, percentage reduction of area, percentage elongation in two inches, and sometimes the Brinell hardness number.

Invariably, however, these figures have all been obtained as a result of tests of test specimens of approximately $\frac{1}{2}$ in. in diameter. They are obtained from testing standard tension test pieces that have been heat-treated either in the test piece size or as $\frac{7}{8}$ or 1-in. round bars, and subsequently machined to standard tension test-piece size.

In no case are these figures representative of the physical property values that are obtained commercially in treating different size sections of these materials. These figures represent the physical properties of hardened small sections, whereas the majority of commercial applications of these materials are for parts of large section, such as gear wheels, driving shafts, crank shafts, axles, etc. These parts are generally heat-treated and it is quite generally recognized that the strength, ductility, etc., which heat treatment will develop in these large size sections, are quite different from the similar properties which will be obtained in smaller sections by similar heat-treatment methods.

So far as the author is aware, very little work has been done on determining the effect of size on the physical properties developed by heat treatment. The variables affecting the hardening of a piece of steel other than the size of the piece being quenched, namely, the initial quenching temperature and the character of the cooling medium, have been made the subject of a vast amount of research. Literature and data concerning the proper hardening temperature, that is, the temperature from which to quench these different alloy steels, are inexhaustible. Also the effect of different cooling mediums with their many variables has been broadly studied, but the effect of the size of the piece being quenched, in its relation to the physical properties developed, has received very little attention. And it was with a view to obtaining some definite information on this point that the experiments hereinafter described were undertaken.

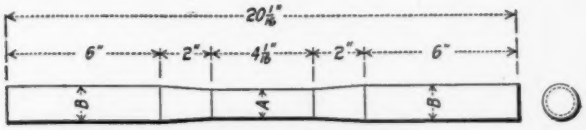
The only published work on the effect of size, which we have been able to find, is in the Mayari Steel catalog of the Pennsylvania Steel Co., second edition, pages 33–36. Here are given some results of tests of two steels of the Mayari or natural alloy chrome-nickel type. These tests were on 0.28-per-cent-carbon and 0.39-per-cent-carbon steels, containing about 0.45 per cent of chromium. Curves are given showing the relation that exists between the four physical properties,—elastic limit, tensile strength, reduction of area, and elongation, respectively,—and the sizes of the pieces being quenched.

The pieces were quenched, for the first steel, in sizes from 1 to 6 in. round; for the second steel, from $\frac{7}{8}$ to $4\frac{1}{8}$ in. round. These data are very interesting but incomplete, inasmuch as the heat treatment to which the bars were subjected is not given; also, the figures are not accurate for the real physical properties developed in the pieces, for, quoting from the catalog, "on the bars over 2 in. in diameter, the tests were taken one-half the distance from the center to the outside, and on the smaller rounds they were taken from the center." This is the trouble with all of the tension-test data available at present.

OUTLINE OF EXPERIMENT.

The plan of our experiment was to actually test full-size test pieces from $\frac{1}{2}$ in. round up to $1\frac{3}{4}$ in. round, increasing the

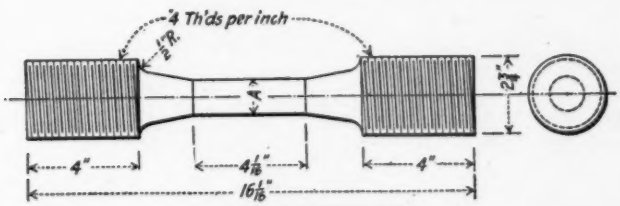
diameter $\frac{1}{8}$ in. from piece to piece. This latter size was about the maximum that could be satisfactorily tested in the 800,000-lb. Emery testing machine at the Watertown Arsenal at Watertown, Mass. And it was about as large as is ordinarily used in the majority of automobile constructions.



Test Piece No.	"A"	"B"
1-2-23	0."500	0."750
3-4-24	0."625	0."875
5-6-25	0."750	1."000
7-8-26	0."875	1."125
9-10-27	1."000	1."250
11-12-28	1."125	1."375

FIG. 1.

Two suitable and representative steels were to be selected, composition to be carefully checked and suitable test pieces to be prepared. These were to be carefully heat-treated, care



Test Piece No.	"A"
29-35	1."125
13-14-30-36	1."250
15-16-31-37	1."375
17-18-32-38	1."500
19-20-33-39	1."625
21-22-34-40	1."750

FIG. 2.

being exercised to keep all conditions constant, so that the variation in the size of the test pieces would be the only variable. After treatment the pieces were to be carefully tested in tension and studied microscopically with the hope of drawing some valuable information from the data obtained.

Selection and Analysis of Stock.—It was decided to carry out these investigations with the following two steels: (1) a 0.20-per-cent-carbon, 3.5-per-cent-nickel steel, and (2) a 0.40-per-cent-carbon, type "D," chrome-vanadium steel. The nickel steel was taken from the stock of the H. H. Franklin Manufacturing Co. The bars used were all finished hot-rolled and annealed. The Brinell hardness number of these original nickel-steel bars was about 160.

The chrome-vanadium steel was most kindly furnished free of charge for this purpose by the Halcomb Steel Co. It was all electric-furnace steel, furnished in two sizes, $1\frac{7}{8}$ in. round and $2\frac{7}{8}$ in. round, and finished hot-rolled and annealed.

Of the nickel-steel series, test pieces Nos. 23 to 28, inclusive, were made from two bars $2\frac{1}{16}$ in. round, which analyzed as follows:

	Carbon, per cent.	Manganese, per cent.	Nickel, per cent.
Bar No. 3	0.224	0.737	(within specification
Bar No. 6	0.218	0.745	3.25 to 3.75).

Test pieces Nos. 29 to 34, inclusive, were made from two bars $2\frac{3}{4}$ in. round, which analyzed as follows:

	Carbon, per cent.	Manganese, per cent.	Nickel, per cent.
Bar No. 253	0.22	0.73	3.72
Bar No. 254	0.22	Not determined.	Not determined.

Test pieces Nos. 35 to 40, inclusive, were made from one bar $2\frac{3}{4}$ in. round, which analyzed as follows:

Carbon	0.19	per cent
Manganese	0.69	"
Nickel	3.46	"
Silicon	0.11	"
Sulphur	0.014	"
Phosphorus	0.019	"

Subsequent analysis of test pieces Nos. 28 and 29 made after the pieces had been tested gave the following results:

	Test Piece No. 28.	Test Piece No. 29.
Carbon	0.23 per cent	0.23 per cent
Manganese	0.72 "	0.62 "
Nickel	3.48 "	3.44 "
Silicon	0.18 "	0.23 "
Sulphur	0.032 "	0.011 "
Phosphorus	0.041 "	0.011 "



TABLE I.—RESULTS OF PHYSICAL TES

Test Piece No.	Mark.	Diameter, in.		Measured Elongation in 4 in., in.	Load, lb.		Unit Stress, lb. per sq. in.		Reduction of Area, per cent.	Elongation in 4 in., per cent.	Bri Hard Nu
		Original.	After Break.		Elastic Limit.	Maximum Strength.	Elastic Limit.	Maximum Strength.			Outside.
1	V-1	0.500	0.420	0.18	43 000	51 500	219 000	262 000	29.4	4.5	495
2	V-2	0.500	0.408	0.20	43 000	50 670	219 000	258 000	33.4	5.0	477
3	V-3	0.625	0.531	0.17	68 000	78 400	221 500	255 000	27.8	4.25	477
4	V-4	0.625	0.532	0.20	65 000	79 500	212 000	259 000	27.5	5.00	511
5	V-5	0.750	0.638	0.19	93 000	114 200	210 000	258 500	27.6	4.75	514
6	V-6	0.750	0.642	0.11	94 000	114 000	212 800	258 000	26.8	2.75	514
7	V-7	0.875	0.746	0.08	122 000	149 200	203 000	248 000	27.3	2.00	483
8	V-8	0.875	0.706	0.22	119 000	140 000	198 000	233 000	34.9	5.5	450
9	V-9	1.000	0.817	0.20	165 800[a]	172 000	211 000[a]	219 000	33.2	5.0	489
10	V-10	1.000	0.826	0.11	165 800[a]	172 000	211 000[a]	219 000	31.8	2.75	509
11	V-11	1.125	0.889	0.34	171 000[a]	188 200	172 000[a]	189 500	37.6	8.2	388
12	V-12	1.125	0.914	0.30	173 000[a]	201 500	174 000[a]	203 000	34.0	7.5	415
13	V-1-T	1.250	1.000	0.41	Not Recorded	237 200	.....	193 300	36.0	10.25	413
14	V-2-T	1.250	1.070	0.18	180 000	238 400	147 000	194 300	26.75	4.5	420
15	V-3-T	1.375	1.100	0.40	187 500	261 000	126 300	176 000	35.8	10.0	376
16	V-4-T	1.375	1.120	0.45	195 000	265 700	131 500	179 000	33.6	11.25	360
17	V-5-T	1.500	1.260	0.52	232 500	309 400	131 500	175 000	29.5	13.0	364
18	V-6-T	1.500	1.220	0.50	245 000	311 700	138 600	176 200	33.9	12.5	369
19	V-7-T	1.625	1.330	0.57	260 000	363 600	125 400	175 200	33.0	14.25	376
20	V-8-T	1.625	1.290	0.51	275 000	375 900	132 500	181 300	37.0	12.75	394
21	V-9-T	1.750	1.400	0.72	305 000	412 200	126 800	171 400	36.0	18.0	353
22	V-10-T	1.750	1.480	0.53	300 000	427 300	125 000	177 700	28.5	13.25	378

[a] These values are for the yield point.

TABLE II.—RESULTS OF PHY

Test Piece No.	Mark.	Diameter, in.		Measured Elongation in 4 in., in.	Load, lb.		Unit Stress, lb. per sq. in.		Reduction of Area, per cent.	Elongation in 4 in., per cent.	Bi Ha Nu
		Original.	After Break.		Elastic Limit.	Maximum Strength.	Elastic Limit.	Maximum Strength.			Outside.
13	V-1-T	1.250	1.000	0.41	Not		237 200	.....	193 300	36.0	10.2

ICAL TESTS; CHROME-VANADIUM-STEEL SERIES.

Elongation in 4 in., per cent.	Brinell Hardness Number. Outside.	Brinell Hardness Number. Center.	Description of Fracture.	Place and Method of Testing.	Remarks.
4.5	495	477	Fine grained, uniform, nearly complete cup and cone fracture.	Halcomb Steel Co. 100 000-lb. Olsen.	
5.0	477	477	Fine grained, uniform, nearly complete cup and cone fracture.	"	
4.25	477	444	Medium grained, rough, irregular cup and cone fracture.	Wyman & Gordon Co. 200 000-lb. Olsen.	
5.00	511	450	Medium grained, rough, nearly complete cup and cone fracture.	"	
4.75	514	477	Slightly coarse grained, rough, part cup and cone fracture.	"	
2.75	514	444	Slightly coarse grained, rough, part cup and cone fracture.	"	Elongation inaccurate, Broke at gage mark.
2.00	483	444	Medium grained, complete cup and cone fracture.	"	"
5.5	450	415	Medium grained, rough, part cup and cone fracture.	"	
5.0	489	415	Medium grained, rough, part cup and cone fracture.	Worcester Polytechnic Institute 400 000-lb. Olsen.	
2.75	509	432	Medium grained, rough, complete cup and cone fracture.	"	Elongation inaccurate, Broke near gage mark
8.2	388	344	Slightly coarse grained, rough, irregular cup and cone fracture.	"	
7.5	415	353	Medium grained, a little fiery, part cup and cone fracture.	"	
10.25	413	320	Quite coarse grained, rough, part cup and cone fracture.	Watertown Arsenal 800 000-lb. Emery.	
4.5	420	333	Quite coarse grained, even, part cup and cone fracture.	"	Elongation inaccurate, Broke at gage mark.
10.0	376	331	Quite coarse grained, looks slightly spongy in center, complete cup and cone fracture.	"	
11.25	360	325	Quite coarse grained, looks slightly spongy in center, complete cup and cone fracture.	"	
13.0	364	340	Quite coarse grained, a little fiery, complete cup and cone fracture.	"	
12.5	369	342	Quite coarse grained, complete cup and cone fracture.	"	
14.25	376	331	Quite coarse grained, irregular cup and cone fracture.	"	
12.75	394	351	Quite coarse grained, looks slightly spongy in center, irregular cup and cone fracture.	"	
18.0	353	333	Quite coarse grained, looks slightly spongy in center, part cup and cone fracture.	"	
13.25	378	338	Quite coarse grained, irregular cup and cone fracture.	"	

OF PHYSICAL TESTS; NICKEL-STEEL SERIES.

Elongation in 4 in., per cent.	Brinell Hardness Number. Outside.	Brinell Hardness Number. Center.	Description of Fracture.	Place and Method of Testing.	Remarks.

13	V-1-T	1.250	1.000	0.41	Not Recorded	237 200	.....	193 300	36.0	10.25
14	V-2-T	1.250	1.070	0.18	180 000	238 400	147 000	194 300	26.75	4.5
15	V-3-T	1.375	1.100	0.40	187 500	261 000	126 300	176 000	35.8	10.0
16	V-4-T	1.375	1.120	0.45	195 000	265 700	131 500	179 000	33.6	11.25
17	V-5-T	1.500	1.260	0.52	232 500	309 400	131 500	175 000	29.5	13.0
18	V-6-T	1.500	1.220	0.50	245 000	311 700	138 600	176 200	33.9	12.5
19	V-7-T	1.625	1.330	0.57	260 000	363 660	125 400	175 200	33.0	14.25
20	V-8-T	1.625	1.290	0.51	275 000	375 900	132 500	181 300	37.0	12.75
21	V-9-T	1.750	1.400	0.72	305 000	412 200	126 800	171 400	36.0	18.0
22	V-10-T	1.750	1.480	0.53	300 000	427 300	125 000	177 700	28.5	13.25

[a] These values are for the yield point.

TABLE II.—RESULTS OF

Test Piece No.	Mark.	Diameter, in.		Measured Elongation in 4 in., in.	Load, lb.		Unit Stress, lb. per sq. in.		Reduction of Area, per cent.	Elongation in 4 in., per cent.
		Original.	After Break.		Elastic Limit.	Maximum Strength.	Elastic Limit.	Maximum Strength.		
23	N-1	0.500	0.373	0.28	23 000(?)	41 100	117 000(?)	209 500	44.3	7.0
24	N-2	0.625	0.483	0.31	39 050(?)	63 250	127 000(?)	206 000	40.25	7.75
25	N-3	0.750	0.596	0.30	70 000(?)	88 600	158 500(?)	200 500	36.8	7.50
26	N-4	0.875	0.717	0.31	92 000(?)	111 200	153 000(?)	185 000	32.8	7.75
27	N-5	1.000	0.820	0.34	94 000(?)	140 000	119 500(?)	178 000	32.8	8.50
28	N-6	1.125	0.952	0.32	107 500	156 800	108 200	157 800	28.4	8.0
29	N-1-T	1.125	0.830	0.82	42 500	112 000	42 750	112 700	45.6	20.5
30	N-2-T	1.248	0.920	0.87	70 000	136 600	57 200	111 700	45.7	21.75
31	N-3-T	1.370	1.000	1.03	82 500	157 500	56 000	106 800	45.7	25.75
32	N-4-T	1.490	1.080	1.03	110 000	186 100	63 000	106 700	47.5	25.75
33	N-5-T	1.623	1.180	1.07	123 500	217 200	59 700	105 000	47.1	26.75
34	N-6-T	1.711	1.240	1.07	150 000	249 600	65 200	108 500	47.5	26.75
35	35	1.125	0.830	0.81	45 000	105 900	45 300	106 500	45.6	20.2
36	36	1.250	0.890	0.95	55 000	128 100	44 800	104 500	49.3	23.7
37	37	1.375	0.940	0.99	76 000	152 400	51 200	102 700	53.2	24.7
38	38	1.500	1.040	1.05	87 500	189 800	49 500	107 400	52.0	26.2
39	39	1.625	1.34	0.76	100 000	206 700	48 300	99 700	32.0	19.0
40	40	1.750	1.40	1.05	122 550	238 300	50 900	99 100	34.8	26.2

.0	10.25	413	320	Quite coarse grained, rough, part cup and cone fracture.	Watertown Arsenal 800 000-lb. Emery.	
.75	4.5	420	333	Quite coarse grained, even, part cup and cone fracture.	"	Elongation inaccurate. Broke at gage mark.
.8	10.0	376	331	Quite coarse grained, looks slightly spongy in center, complete cup and cone fracture.	"	
.6	11.25	360	325	Quite coarse grained, looks slightly spongy in center, complete cup and cone fracture.	"	
.5	13.0	364	340	Quite coarse grained, a little fiery, complete cup and cone fracture.	"	
.9	12.5	369	342	Quite coarse grained, complete cup and cone fracture.	"	
.0	14.25	376	331	Quite coarse grained, irregular cup and cone fracture.	"	
.0	12.75	394	351	Quite coarse grained, looks slightly spongy in center, irregular cup and cone fracture.	"	
.0	18.0	353	333	Quite coarse grained, looks slightly spongy in center, part cup and cone fracture.	"	
.5	13.25	378	333	Quite coarse grained, irregular cup and cone fracture.	"	

LTS OF PHYSICAL TESTS; NICKEL-STEEL SERIES.

duc-n of rea, er nt.	Elon-gation in 4 in., per cent.	Brinell Hardness Number. Out-side.	Brinell Hardness Number. Cen-ter.	Description of Fracture.	Place and Method of Testing.	Remarks.
.3	7.0	394	418	Slightly coarse grained, spongy looking, irregular cup and cone fracture.	Halcomb Steel Co. 100 000-lb. Olsen.	Elongation inaccurate. Broke near gage mark.
.25	7.75	394	415	Slightly coarse grained, spongy looking, complete cup and cone fracture.	"	Rather poor stress-strain curve.
.8	7.50	410	369	Slightly coarse grained, spongy looking, part cup and cone fracture.	Wyman & Gordon Co. 200 000-lb. Olsen.	Very poor stress-strain curve.
.8	7.75	410	344	Slightly coarse grained, slightly fiery, spongy, irregular cup and cone fracture.	"	Very poor stress-strain curve.
.8	8.50	385	312	Slightly coarse grained, spongy, slightly fiery, irregular cup and cone fracture.	"	Rather poor stress-strain curve.
.4	8.0	406	275	Slightly coarse grained, fiery, slightly spongy, part cup and cone fracture.	"	Very poor stress-strain curve. Broke near gage mark.
.6	20.5	241	242	Quite coarse grained, fiery, slightly spongy, part cup and cone fracture.	Watertown Arsenal 800 000-lb. Emery.	
.7	21.75	237	248	Quite coarse grained, entirely spongy, part cup and cone fracture.	"	
.7	25.75	239	242	Very coarse grained, entirely spongy, part cup and cone fracture.	"	
.5	25.75	241	241	Quite coarse grained, entirely spongy, nearly complete cup and cone fracture.	"	
.1	26.75	228	228	Quite coarse grained, entirely spongy, nearly complete, cup and cone fracture.	"	
.5	26.75	248	228	Quite coarse grained, entirely spongy, nearly complete cup and cone fracture.	"	
.6	20.2	248	255	Slightly coarse grained, tough, part cup and cone, irregular fracture.	"	
.3	23.7	241	228	Slightly coarse grained, finer than No. 35, part cup and cone, irregular fracture.	"	
.2	24.7	228	228	Slightly coarse grained, nearly complete cup and cone, irregular fracture.	"	
.0	26.2	262	235	Slightly coarse grained, nearly complete cup and cone, irregular fracture.	"	
.0	19.0	228	269	Very uncommon fracture, entire surface looks sheared, very irregular cup and cone.	"	
.8	26.2	248	248	Exactly like No. 39.	"	

These test pieces were of the same diameter on the pulling section, namely, $1\frac{1}{8}$ in., though No. 28 was made as shown in Fig. 1 and No. 29 was made as in Fig. 2. They both received the same heat treatment but gave quite different physical results, which may be seen in Table II (Plate XII).

The bars for the chrome-vanadium pieces were all rolled from billets from the same heat of electric-furnace steel. The bars furnished were $1\frac{7}{8}$ in. round and $2\frac{7}{8}$ in. round, with which the following analyses were supplied:

	$1\frac{7}{8}$-IN. RD. BARS.	$2\frac{7}{8}$-IN. RD. BARS.
Carbon	0.42 per cent	0.43 per cent
Manganese	0.73 "	0.70 "
Chromium	0.89 "	0.87 "
Vanadium	0.19 "	0.19 "
Silicon	0.27 "	0.27 "
Sulphur	0.015 "	0.015 "
Phosphorus	0.010 "	0.010 "

Subsequent analysis of test pieces Nos. 12 and 13 made after the pieces had been tested showed the following results:

	TEST PIECE NO. 12.	TEST PIECE NO. 13.
Carbon	0.43 per cent	0.42 per cent
Manganese	0.71 "	0.73 "
Chromium	0.88 "	0.88 "
Vanadium	0.20 "	0.24 "
Silicon	0.26 "	0.27 "
Sulphur	0.019 "	0.022 "
Phosphorus	0.004 "	0.003 "

Test piece No. 12 was made from a $1\frac{7}{8}$-in. round bar and test piece No. 13 was made from a $2\frac{7}{8}$-in. round bar.

Machining of Test Pieces.—In both the nickel-steel and the chrome-vanadium-steel series certain of the pieces were machined up to be pulled in friction grips, and the remainder of each series was prepared with threaded ends to fit specially prepared holders which were made for the 800,000-lb. hydraulic Emery testing machine of the Watertown Arsenal. The pieces for friction grips were made up as shown in Fig. 1. The pieces with threaded ends were made up as shown in Fig. 2.

All test pieces were made up with 0.040 in. left over the finishing size on the pulling section. They were then ground accurately to size after heat treating.

Heat Treatment.—When machined, the test pieces were very carefully heat-treated. The heating was done in a gas-fired open-muffle furnace with combustion chamber under the floor. The furnace was a No. 5 oven furnace of the American Gas Furnace Co. Temperatures were indicated by a carefully calibrated Le Chatelier type of platinum-platinum-rhodium thermo-couple with a constant cold junction temperature. A

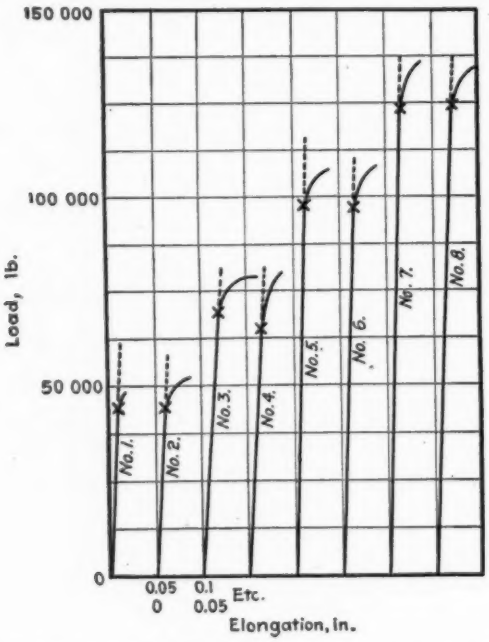


FIG. 3.—Autographic Load-Deformation Curves; Chrome-Vanadium-Steel Series.

fairly uniform temperature was maintained throughout the heating chamber. The fire end of the couple, which was protected by a porcelain protection tube, was located very close to the pieces being treated, so that the temperature of the hot end of the couple was undoubtedly the same as the temperature of the work. The test pieces were treated in the furnace two to six at a time depending upon the size, and located close under the thermo-couple end.

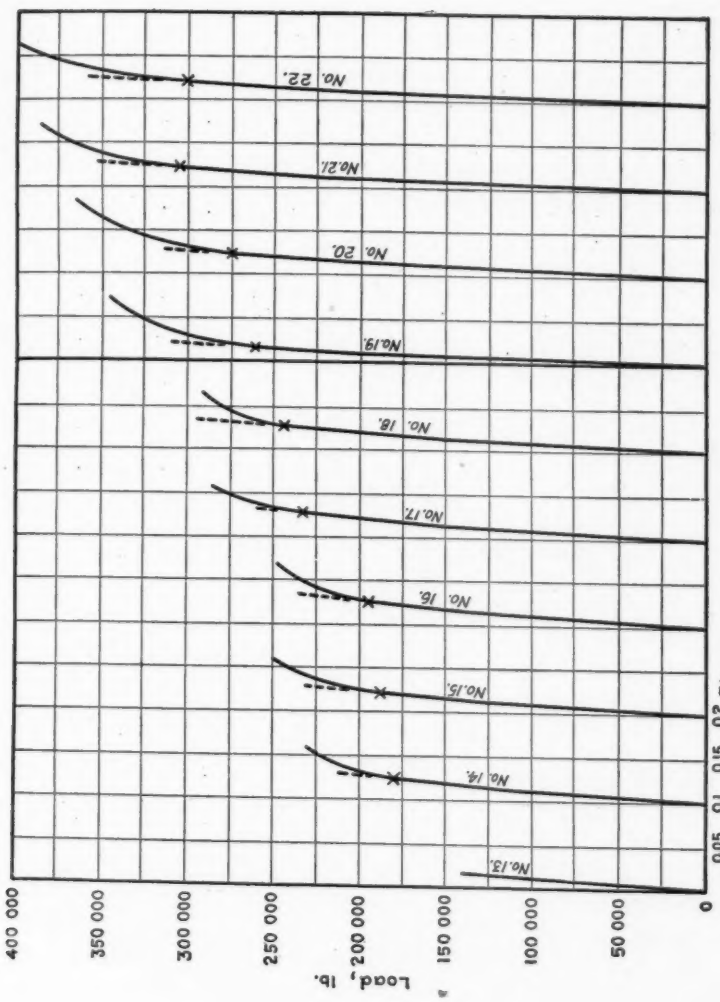


FIG. 4.—Load-Deformation Curves Plotted from Data; Chrome-Vanadium-Steel Series.

The treatments given were as follows:

For the nickel-steel series, heated to 1550° F. and quenched in oil—not drawn.

For the chrome-vanadium-steel series, heated to 1650° F., quenched in oil, and drawn for 60 minutes at 500° F.

The pieces were put into the furnace when it was about 150° F. below the desired quenching temperature and brought up to heat slowly with the furnace. The pieces were held at the quenching temperature for 20 to 30 minutes. They were then carefully quenched vertically one at a time in raw linseed oil.

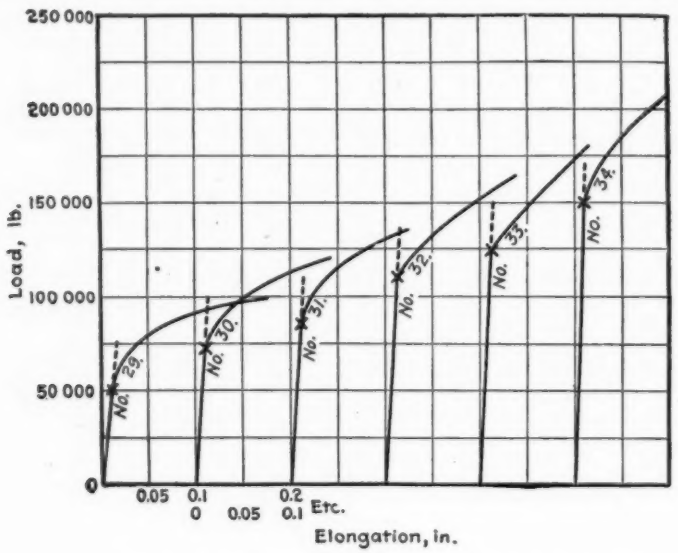


Fig. 5.—Load-Deformation Curves Plotted from Data; Nickel-Steel Series.

The nickel-steel series were then simply washed in hot soda water and sand-blasted.

The chrome-vanadium-steel series were heated in a hot oil bath for a period of 60 minutes at a temperature of 500° F. The pieces were held away from the sides and bottom of the bath to prevent overheating. The object of this drawing operation was to give the pieces sufficient ductility so that they would not break short in testing.

When drawn the pieces were cleaned and sand-blasted.

Grinding.—After heat treatment the pieces were finish-ground to size.

Testing.—The testing of these pieces was done as shown in Tables I and II (Plate XII).

All pieces pulled with friction grips (Fig. 1) were tested on Olsen universal testing machines of 100,000, 200,000, and 400,000-lb. capacity; autographic stress-strain curves being taken on all but the four (Nos. 9, 10, 11, 12) which were pulled at the Worcester Polytechnic Institute. In some cases the

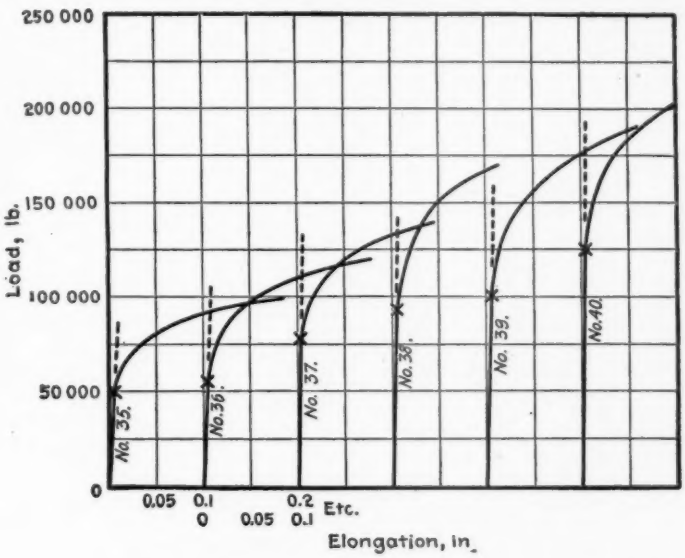


Fig. 6.—Load-Deflection Curves Plotted from Data; Duplicate of Nickel-Steel Series.

curves obtained were not very satisfactory, as is hereinafter noted.

The threaded test pieces (Fig. 2) were all tested at the Watertown Arsenal, on the 800,000-lb. Emery testing machine. The method of testing was to apply the load in increments of 10,000 lb., measuring the extension due to each new application of load by means of an electrical contact micrometer extensometer. Stress-strain curves were then drawn up from these figures.

In Figs. 3 to 6, inclusive, are reproduced the stress-strain or load-deformation curves for all the pieces tested in this investi-

TABLE III.—BRINELL HARDNESS TESTS.

Test Piece No.	Mark.	Outside.		Center.		¼ in. from Center.		¼ in. from Edge.	
		Diameter, mm.	Hardness Number.	Diameter, mm.	Hardness Number.	Diameter, mm.	Hardness Number.	Diameter, mm.	Hardness Number.
CHROME-VANADIUM-STEEL SERIES.									
1	V-1	2.75	495	2.80	477	....	....	....	....
2	V-2	2.80	477	2.80	477	....	....	....	....
3	V-3	2.80	477	2.90	444	....	....	....	....
4	V-4	2.71	511	2.88	450	....	....	....	....
5	V-5	2.70	514	2.80	477	....	....	....	....
6	V-6	2.70	514	2.90	444	....	....	....	....
7	V-7	2.78	483	2.90	444	....	....	....	....
8	V-8	2.88	450	3.00	415	....	....	....	....
9	V-9	2.77	489	3.00	415	....	....	....	....
10	V-10	2.72	509	2.94	432	....	....	....	....
11	V-11	3.10	388	3.29	344	....	....	....	....
12	V-12	3.00	415	3.25	353	....	....	....	....
13	V-1-T	3.01	413	3.41	320	3.32	338	....	....
14	V-2-T	2.98	420	3.32	338	3.12	385	....	....
15	V-3-T	3.15	376	3.35	331	3.33	335	....	....
16	V-4-T	3.22	360	3.38	325	3.32	338	....	....
17	V-5-T	3.20	364	3.31	340	3.30	342	3.30	342
18	V-6-T	3.18	369	3.30	342	3.28	346	3.23	356
19	V-7-T	3.15	376	3.35	331	3.30	342	3.40	322
20	V-8-T	3.08	394	3.26	351	3.31	340	3.30	342
21	V-9-T	3.25	353	3.34	333	3.30	342	3.30	342
22	V-10-T	3.14	378	3.32	338	3.40	322	3.36	330
NICKEL-STEEL SERIES.									
23	N-1	3.08	394	2.99	418	....	....	....	....
24	N-2	3.08	394	3.00	415	....	....	....	....
25	N-3	3.02	410	3.18	369	....	....	....	....
26	N-4	3.02	410	3.29	344	....	....	....	....
27	N-5	3.12	385	3.45	312	....	....	....	....
28	N-6	3.03	406	3.66	275	....	....	....	....
29	N-1-T	3.90	241	3.88	242	3.90	241	....	....
30	N-2-T	3.93	237	3.84	248	3.86	246	....	....
31	N-3-T	3.91	239	3.88	242	3.90	241	....	....
32	N-4-T	3.90	241	3.90	241	3.87	244	4.06	222
33	N-5-T	4.00	228	4.00	228	3.99	229	4.12	215
34	N-6-T	3.84	248	4.00	228	3.90	241	4.10	217
35	35	3.85	248	3.80	255	4.15	212	4.25	202
36	36	3.90	241	4.00	228	4.00	228	4.25	202
37	37	4.00	228	4.00	228	4.00	228	4.15	212
38	38	3.75	262	3.95	235	4.05	223	4.20	207
39	39	4.00	228	3.70	269	4.05	223	4.15	212
40	40	3.85	248	3.85	248	4.10	217	4.15	212

gation except for test pieces Nos. 9 to 12 and 23 to 28, inclusive. Pieces Nos. 9 to 12 were tested on a 400,000-lb. machine which was not equipped to take autographic curves; hence these

cannot be given. In the column of Table I headed "Elastic Limit," the value for the yield point of Nos. 9, 10, 11, and 12 is given, rather than the proportionality limit which is given in the other cases. This yield point was measured by the "drop of the beam" of the testing machine.

The curves for test pieces Nos. 23 to 28 are not given, as these curves were not satisfactory, due to a defect in the autographic extensometer mechanism at the time they were taken. The values given in the column "Elastic Limit" in Table II for these pieces Nos. 23 to 28 were taken from the curves obtained. They are not reliable, however, as the curves themselves are not reliable.

The curves shown in Fig. 3 are reproduced from the autographic curves obtained at the time of testing these pieces. The curves of Figs. 4 to 6, inclusive, are drawn up from the data taken at the time of testing these pieces. On all these curves we have attempted to show the point of true elastic limit; that is, the point where the proportionality of stress to strain ceases to be rectilinear, and this is the point we have given in Tables I and II as the elastic limit.

After the tension tests were completed the broken pieces were cut up so that Brinell hardness tests could be made across the section. (See Table III.)

Also, sections entirely across the diameter of the tested pieces were prepared for microscopic examination. (See microphotographs, Figs. 11 to 28, Plates XIII, XIV and XV, and notes of visual examination in the appendix to this paper.) All microsections and Brinell hardness tests were made on an unstrained portion of the pulling section.

Consideration of Results.—The results of the tension tests, Brinell hardness numbers for the outside and the center of the pieces, and the descriptions of the fractures are embodied in Tables I and II. Table I gives the results from the chrome-vanadium series and Table II gives the results from the nickel-steel series. Table III gives Brinell hardness numbers for both series of steels taken across the pulling section and on the side of the piece. All Brinell tests were made on an Alpha machine.

An examination of Table I will reveal at a glance that there is a falling off in maximum strength of about 85,000

lb. per sq. in. from the $\frac{1}{2}$ to the $1\frac{3}{4}$-in. test pieces. This is a decrease of from 260,000 to 174,000 lb. per sq. in. or about 33 per cent. There is an even greater falling off in the elastic limit from the smallest to the largest sizes. Here the decrease is from 219,000 to 126,000 lb. per sq. in., or 42.5 per cent.

The decrease in tensile strength and elastic limit with increase in size of the test piece is best shown graphically. (See curves, Fig. 7.) The dotted curves are drawn between the actual points obtained while the full line curves are idealized.

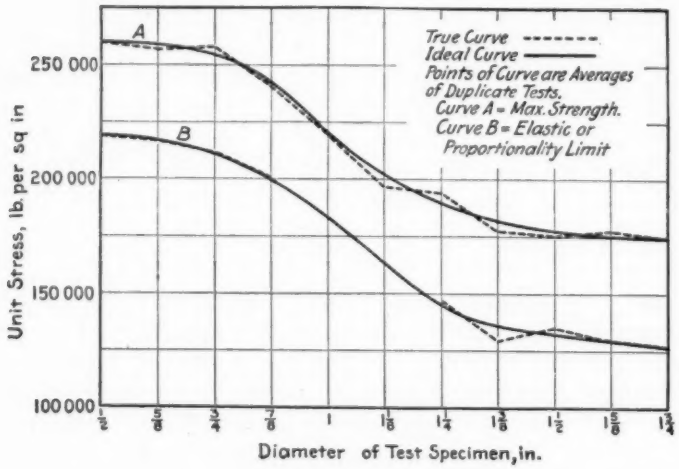


FIG. 7.—Size-Strength Curves, showing the Decrease in Strength with Increase in Size of Hardened Section; Chrome-Vanadium-Steel Series.

The percentage valuations given in Table IV are interesting. They show percentage changes in maximum strength and elastic limit from the values for the $\frac{1}{2}$-in. test pieces. These tables are figured from the values in pounds per square inch obtained by test.

The reduction of area increases slightly from the smaller to the larger sizes, being about 28 per cent for the smaller and about 35 per cent for the larger.

The percentage elongation in 4 in. increases slightly from the smaller to the larger sizes, being about 4 per cent for the

smaller and about 15 per cent for the larger. In some cases, for instance, test pieces Nos. 6 and 7 (see Table I), percentage elongations of only 2 or 3 per cent were obtained. This was because the pieces broke near the end and did not allow the normal elongation to take place.

Still referring to Table I, the Brinell hardness numbers are fairly comparable with the values of tensile strength obtained.

TABLE IV.—PERCENTAGE VALUATIONS.

DIAMETER, IN.	PERCENTAGE OF MAXIMUM STRENGTH OF ½-IN. SPECIMEN.	PERCENTAGE DECREASE OF MAXIMUM STRENGTH.
½	100.0	0.0
⅝	99.0	1.0
¾	99.0	1.0
⅞	92.5	7.5
1	89.3	10.7
1⅛	75.5	24.5
1¼	74.5	25.5
1⅜	68.3	31.7
1½	67.5	32.5
1⅝	67.5	32.5
1¾	67.0	33.0

DIAMETER, IN.	PERCENTAGE OF ELASTIC LIMIT OF ½-IN. SPECIMEN.	PERCENTAGE DECREASE OF ELASTIC LIMIT.
½	100.0	0.0
⅝	99.0	1.0
¾	96.5	3.5
⅞	91.5	8.5
1	....	....
1⅛	....	....
1¼	67.2	32.8
1⅜	59.0	41.0
1½	61.2	38.8
1⅝	58.5	41.5
1¾	57.5	42.5

By referring to the hardness tests made on the outside of the pieces, it is seen that they range from 475 to 510 for the smaller pieces, and for the larger sizes from 355 to 375. The Brinell numbers obtained by making the tests in the centers of the cross-sections of the pieces are uniformly slightly lower than those obtained from tests made on the outside. The fractures throughout the series of the chrome-vanadium test pieces were

similar in character. A good idea of the appearance of these fractures and of the test pieces themselves can be obtained from Fig. 9, in which are shown the broken test pieces of the chrome-vanadium series.

An examination of Table II, which records the results of the tests on the nickel-steel series, will show results which are not as consistent as those of Table I. Considering the first six test pieces, namely, Nos. 23 to 28, the figures for maximum strength are quite consistent and comparable with those shown in Table I. The results are shown graphically in Fig. 8,

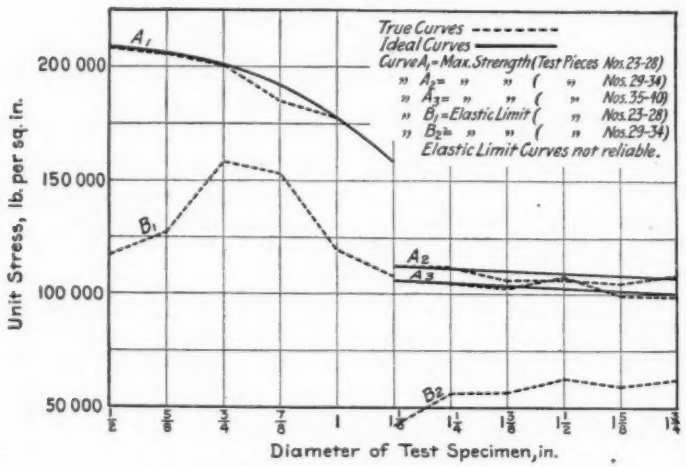
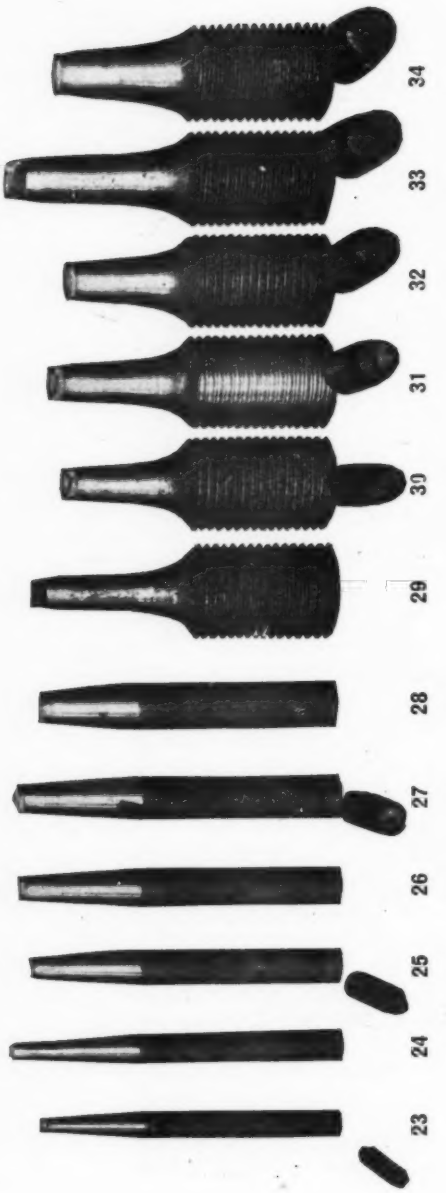


FIG. 8.—Size-Strength Curves; Nickel-Steel Series.

curve A_1. These test pieces varied in size from $\frac{1}{2}$ to $1\frac{1}{8}$ in. in diameter. They were not tested in duplicate and were pulled with friction grips. Test pieces Nos. 29 to 34 and 35 to 40 were really duplicate sets; that is, Nos. 29 and 35 were the same size, Nos. 30 and 36 were the same size, etc. These two sets varied slightly, however, in analysis. The curious part about these pieces is that they did not seem to harden, although they received the same heat treatment as the smaller pieces of this nickel-steel series. Microscopic examination revealed the fact that these pieces were not hardened. (Compare the descriptions of the visual examinations, of specimens Nos. 8

FIG. 9.—Broken Test Pieces, Chrome-Vanadium-Steel Series.



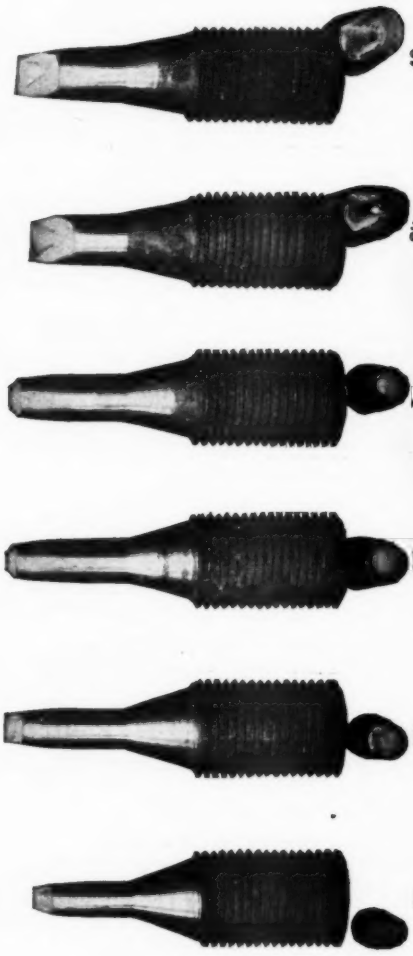


FIG. 10.—Broken Test Pieces, Nickel-Steel Series.

and 9, appended hereto.) These pieces were both of the same diameter on the pulling section, No. 8 however being from test piece No. 28 and No. 9 being from test piece No. 29. Test piece No. 28 was made as indicated in Fig. 1; No. 29 was made as indicated in Fig. 2. The microphotographs of these two pieces show the difference of the two structures. (See Figs. 18 and 19, Plate XIV.)

In considering again test pieces Nos. 23 to 28, the elastic-limit values are not reliable, especially for Nos. 23 and 24. Reduction-of-area percentages for test pieces Nos. 23 to 28 show a consistent decrease with increase of size of the test piece, while the percentage elongation in four inches and Brinell hardness numbers remain practically constant.

In Fig. 10 are shown very well the broken test pieces from the nickel-steel series and the character of fractures obtained.

In explaining the disparity between the nickel-steel series and the chrome-vanadium series the most probable reason seems to be the low carbon content of the nickel steel, with the resultant depreciated tendency to harden when quenched. The large amount of heat stored in the large threaded ends of these test pieces would accentuate this effect.

The author desires to acknowledge his indebtedness to the H. H. Franklin Manufacturing Co., whose liberal policy of fostering research work has made the completion of this work possible. Also he desires to thank the Halcomb Steel Co. for so kindly supplying the chrome-vanadium steel used, and their metallurgist, Mr. H. J. Stagg, Jr., for many helpful suggestions. He further desires to thank the Wyman and Gordon Co. for so kindly permitting the use of their testing machine, and Mr. George MacFarland of that company for his assistance. He wishes to express his deep appreciation of the assistance and cooperation lent in carrying out this work by Mr. F. B. Lounsberry, assistant metallurgist of the H. H. Franklin Manufacturing Co., especially for his careful work in the preparation of the microscopic work of this paper.

[For discussion of this paper, see pp. 525–549.—ED.]

APPENDIX.

MICRO-VISUAL EXAMINATION OF SECTIONS

The etching of all specimens was done in a 5-per-cent alcoholic nitric acid solution and was intended to bring out the best structure of the specimen. The microphotographs are shown in Figs. 11 to 28, inclusive, Plates XII to XV.

CHROME-VANADIUM STEEL SERIES.

SPECIMEN NO. 1; TEST PIECE NO. 1; ½ IN. DIAMETER.

(Figs. 11 and 23.)

This specimen is 0.50-per-cent-carbon chrome-vanadium steel. Heated to 1650° F. and quenched in oil; drawn at 500° F. for 60 minutes.

Magnification 90 diameters.—The specimen shows a uniform, hardened structure. There are bluish etching spots over the surface.

Magnification 430 diameters.—The hardened structure visible at the lower magnification is now broken down into very fine martensite, characteristic of chromium steel. This structure is quite uniform over the whole specimen, the inside varying very slightly or not at all from the outside. The bluish etching spots mentioned before are very slight depressions which had the appearance of being small holes.

Magnification 950 diameters.—At this magnification the martensite is broken down slightly and appears somewhat granular, retaining however, the characteristics of martensite. This structure as a whole is quite characteristic of the martensite of chromium steel when hardened in small sections.

SPECIMEN NO. 2; TEST PIECE NO. 6; ¾ IN. DIAMETER.

(Fig. 12.)

This specimen is 0.50-per-cent-carbon chrome-vanadium steel. Heated to 1650° F. and quenched in oil; drawn at 500° F. for 60 minutes.

Magnification 90 diameters.—The specimen shows a uniform, hardened structure over the whole cross-section, and is quite free from the bluish etching spots noted in specimen No. 1, ½-in. diameter, except in one spot.

Magnification 430 diameters.—At this magnification, the specimen, while it shows a uniform, hardened structure, appears to have more of a troosto-martensitic nature than the smaller specimen; that is, it etches slightly darker than the ½-in. specimen and seems to be tending toward a slightly less hardened structure. The martensite, or troosto-martensite, is very finely divided and is characteristic of a chromium steel. There are a few small spots scattered throughout the structure which etch white.

Magnification 950 diameters.—At this magnification the structure appears quite similar to that of Specimen No. 1. The granular nature of the martensite, or troosto-martensite, is quite evident.

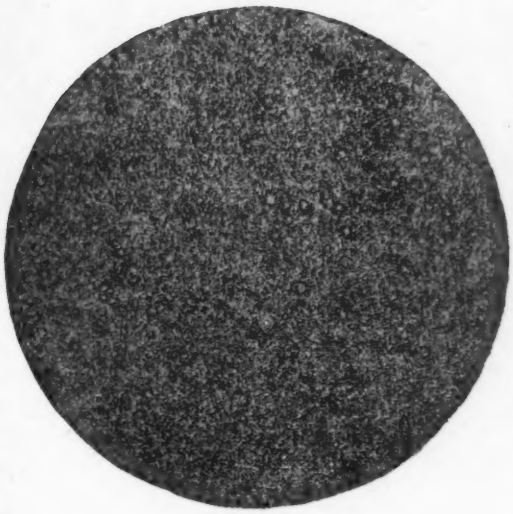


FIG. 11.

Specimen No. 1; Test Piece No. 1;
$\frac{3}{4}$ in. Diameter.
Structure uniformly hardened showing bluish etching spots.

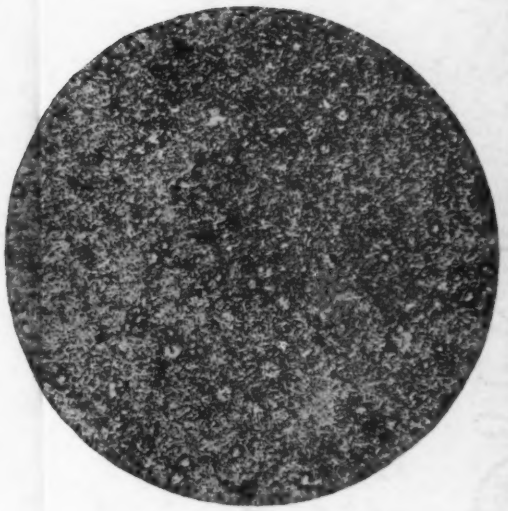


FIG. 12.

Specimen No. 2; Test Piece No. 6;
$\frac{3}{4}$ in. Diameter.
Structure not so uniformly hardened as in Fig. 11. Bluish etching spots evident in this picture are not so prominent over the whole cross-section.



FIG. 14.

Specimen No. 4; Test Piece No. 13;
$1\frac{1}{4}$ in. Diameter.
Structure similar to that of Fig. 13.



FIG. 15.

Specimen No. 5; Test Piece No. 17;
$1\frac{1}{4}$ in. Diameter.
Structure similar to that of Fig. 14, but more uniform.

CHROME-VANADIUM-STEEL SERIES.

NOTE.—All specimens etched with 5-per-cent alcoholic nitric acid solution.

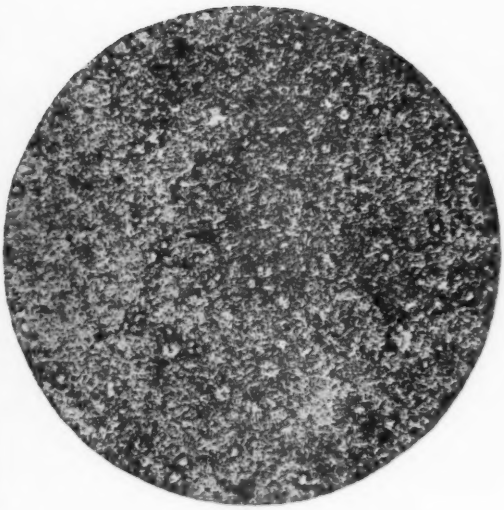


FIG. 12.

Specimen No. 2; Test Piece No. 6;
$\frac{3}{4}$ in. Diameter.
Structure not so uniformly hardened as in Fig. 11. Bluish etching spots evident in this picture are not so prominent over the whole cross-section.

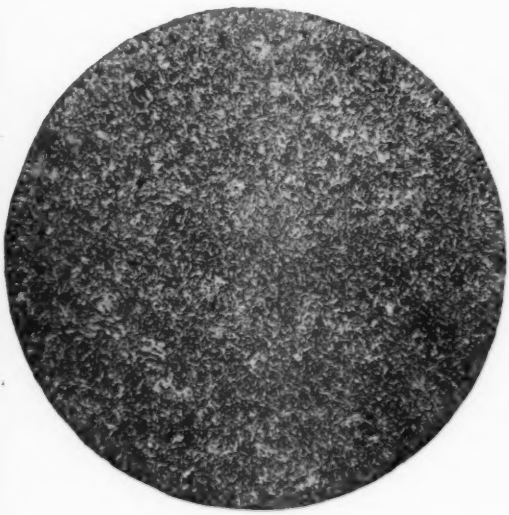


FIG. 15.

Specimen No. 5; Test Piece No. 17;
$1\frac{1}{2}$ in. Diameter.
Structure similar to that of Fig. 14, but more uniform.

CHROME-VANADIUM-STEEL SERIES.

etched with 5-per-cent alcoholic nitric acid solution. Magnification, ×



FIG. 13.
Specimen No. 3; Test Piece No. 12;
1¼ in. Diameter.
Shows tendency towards troostitic structure and coarser crystallization.



FIG. 16.
Specimen No. 6; Test Piece No. 22;
1¼ in. Diameter.
Structure similar to that of Fig. 15, but shows larger and more numerous white patches.

ion, × 100.

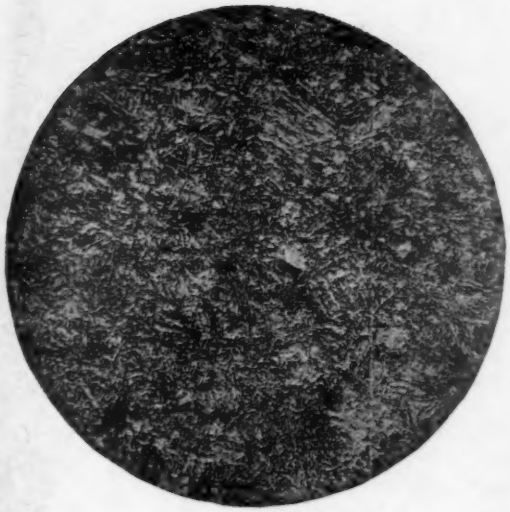


FIG. 17.

Specimen No. 7; Test Piece No. 23;
$\frac{1}{2}$ in. Diameter.
Structure shows very beautiful characteristic martensite.

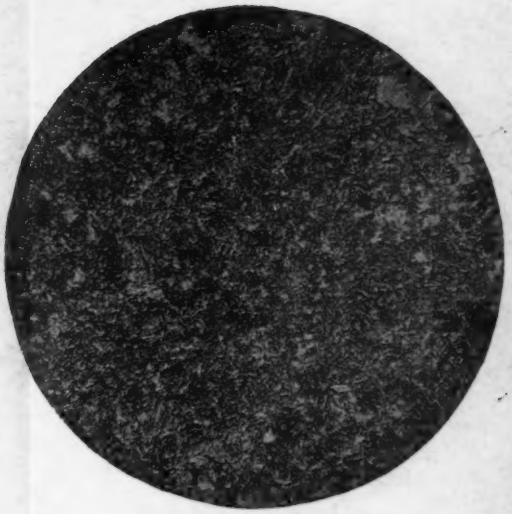


FIG. 18.

Specimen No. 8; Test Piece No. 28;
$1\frac{1}{4}$ in. Diameter.
Structure is martensite, but not so characteristic as in Fig. 17.

NICKEL-STEEL SERIES.

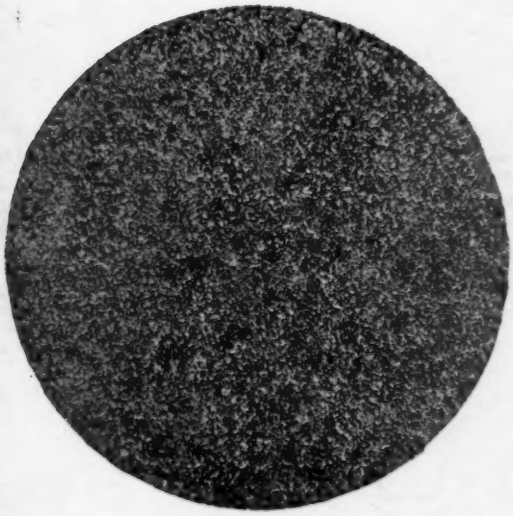


FIG. 19.

Specimen No. 9; Test Piece No. 29;
$1\frac{1}{4}$ in. Diameter.
Structure very fine ferrite and granular pearlite; scarcely resolvable at this magnification.

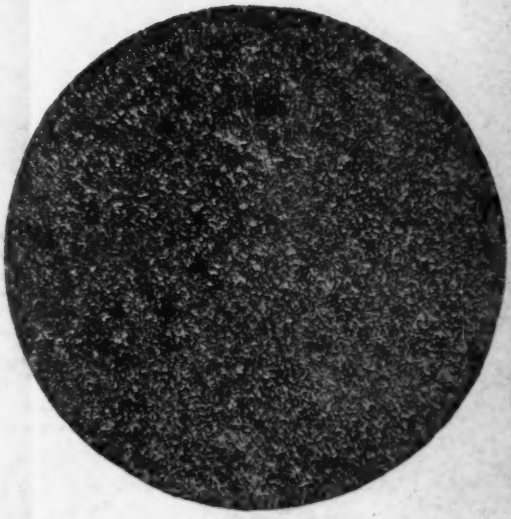


FIG. 20.

Specimen No. 10; Test Piece No. 34;
$1\frac{1}{4}$ in. Diameter.
Structure similar to that of Fig. 19, somewhat coarser.

NICKEL-STEEL SERIES.

NOTE.—All specimens etched in 5-per-cent alcoholic nitric acid solution. Mag

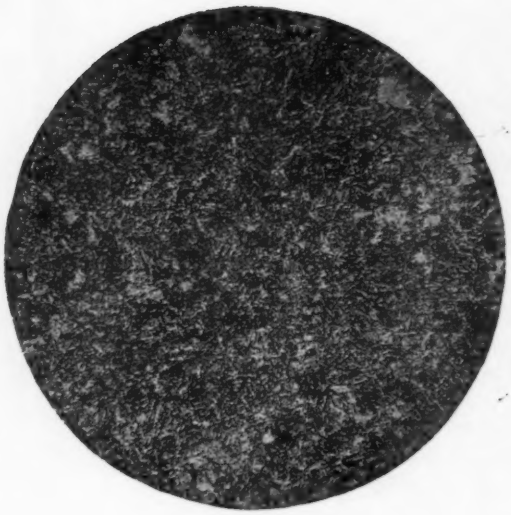


FIG. 18.

Specimen No. 8; Test Piece No. 28;
1¼ in. Diameter.
Structure is martensite, but not so characteristic as in Fig. 17.

L SERIES.

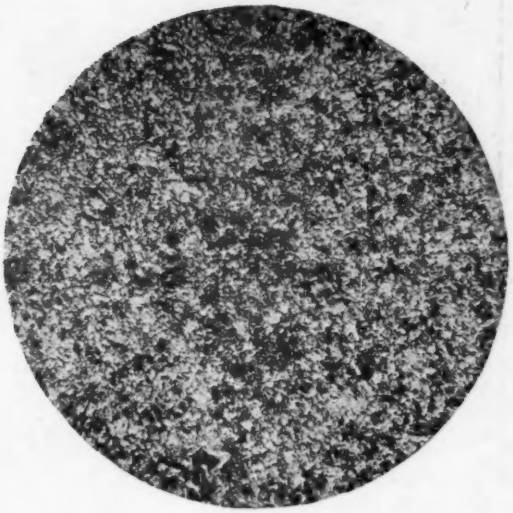


FIG. 21.

Specimen No. 11; Original Bar Stock as Rolled and Annealed.
Structure shows characteristic ferrite and lamellar pearlite of annealed chrome-vanadium steel.

CHROME-VANADIUM-STEEL SERIES.

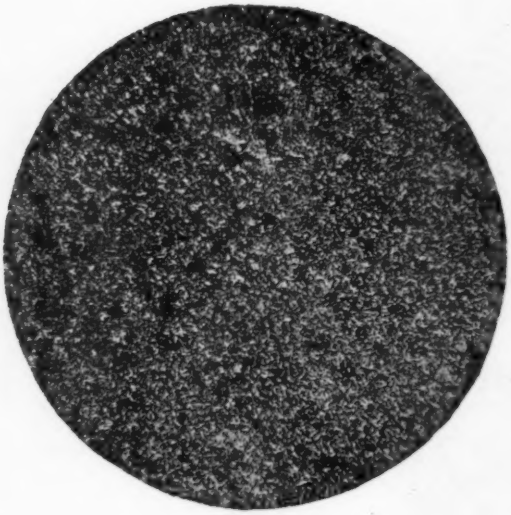


FIG. 20.

Specimen No. 10; Test Piece No. 34;
1¼ in. Diameter.
Structure similar to that of Fig. 19, somewhat coarser.

L SERIES.

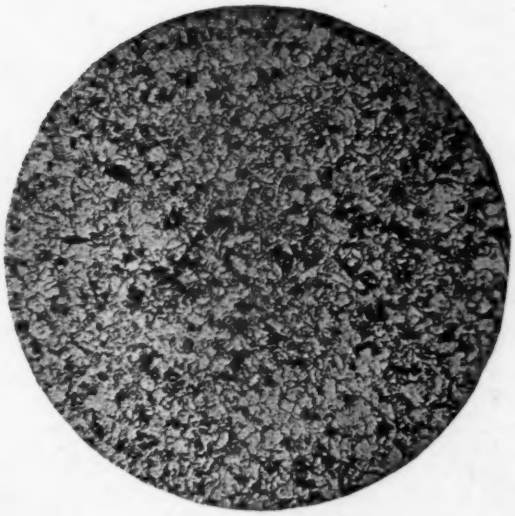


FIG. 22.

Specimen No. 12; Original Bar Stock as Rolled and Annealed.
Structure shows characteristic ferrite and lamellar pearlite of annealed nickel steel.

NICKEL-STEEL SERIES.

etched in 5-per-cent alcoholic nitric acid solution. Magnification, × 100.



FIG. 23.

Specimen No. 1; Test Piece No. 1;
½ in. Diameter (same specimen as in Fig. 11).
Structure very fine martensite, hard to resolve even at this magnification. Characteristic of chromium steels.



FIG. 24.

Specimen No. 6; Test Piece No. 22;
1¾ in. Diameter (same specimen as in Fig. 16).
Appears to be break-down structure of troostitic nature. Generally unresolvable with whitish patches.

CHROME-VANADIUM-STEEL SERIES.



FIG. 26.

Specimen No. 7; Test Piece No. 23;
½ in. Diameter (same specimen as in Fig. 17).
Structure shows beautiful characteristic martensite.



FIG. 27.

Specimen No. 10; Test Piece No. 34;
1¾ in. Diameter (same specimen as in Fig. 20).
Ferrite and granular pearlite structure brought out quite plainly.

NICKEL-STEEL SERIES.

NOTE.—All specimens etched in 5-per-cent alcoholic nitric acid solution.



FIG. 24.

Specimen No. 6; Test Piece No. 22;
1¾ in. Diameter (same specimen as in Fig. 16).
Appears to be break-down structure of troostitic nature. Generally unresolvable with whitish patches.



FIG. 25.

Specimen No. 11; Original Bar Stock as Rolled and Annealed.
(Same specimen as in Fig. 21.)
Poor picture, but shows ferrite and lamellar pearlite.

CHROME-VANADIUM-STEEL SERIES.



FIG. 27.

Specimen No. 10; Test Piece No. 34;
1¾ in. Diameter (same specimen as in Fig. 20).
Ferrite and granular pearlite structure brought out quite plainly.

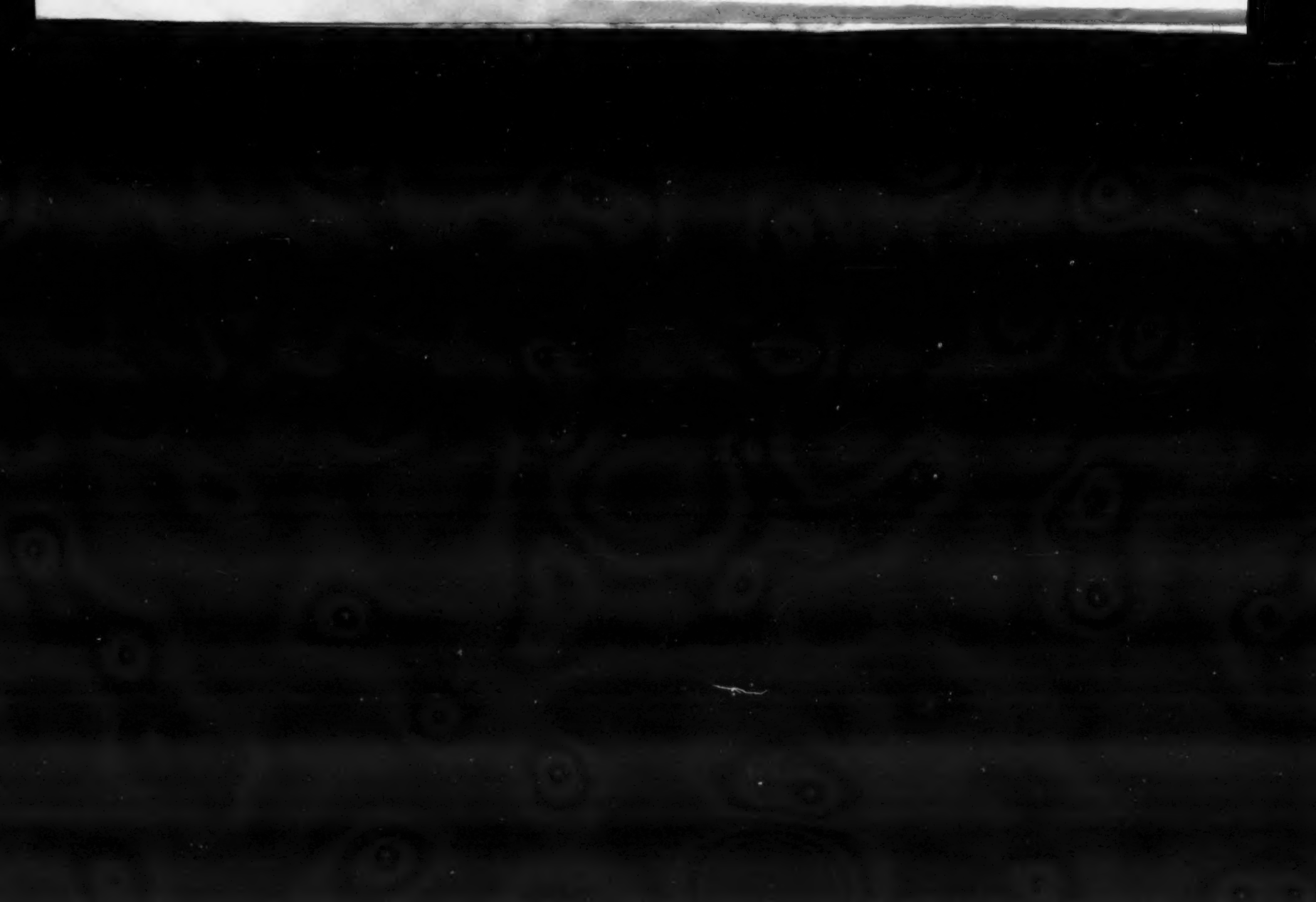


FIG. 28.

Specimen No. 12; Original Bar Stock as Rolled and Annealed.
(Same specimen as in Fig. 22.)
Plainly shows ferrite and lamellar pearlite of original stock. One slag spot visible.

NICKEL-STEEL SERIES.

imens etched in 5-per-cent alcoholic nitric acid solution. Magnification, × 800.



SPECIMEN NO. 3; TEST PIECE NO. 12; 1⅛ IN. DIAMETER.

(Fig. 13.)

This specimen is 0.50-per-cent-carbon chrome-vanadium steel. Heated to 1650° F. and quenched in oil; drawn at 500° F. for 60 minutes.

Magnification 90 diameters.—In general the specimen is darker etching than the preceding ones and seems to be losing its martensitic nature and becoming more nearly a troositic structure. Scattered throughout the troositic material is a material which etches white. There are also numerous small bluish holes, though not so many as in specimen No. 1. On the very outside is a very dark band of troositic material which contains very few of the whitish patches which increase toward the center of the specimen. In the center of the piece is an area which seems to be more free from the whitish patches than the rest of the specimen.

Magnification 430 diameters.—At this magnification the martensitic structure is no longer evident, but the specimen consists almost wholly of unresolvable troostite interspersed with the above-mentioned whitish patches. These whitish patches to all appearances seem to be ferrite, containing small granules of pearlite.

Magnification 950 diameters.—At this magnification the structure seems to consist almost wholly of unresolvable troostite with white patches of what seems to be ferrite. The troostite structure seems to be quite granular in its nature. The needle-like nature of martensite has been entirely lost.

SPECIMEN NO. 4; TEST PIECE NO. 13; 1¼ IN. DIAMETER.

(Fig. 14.)

This specimen is 0.50-per-cent-carbon chrome-vanadium steel. Heated to 1650° F. and quenched in oil; drawn at 500° F. for 60 minutes.

Magnification 90 diameters.—The structure of the specimen is in every way identical with the previous specimen, except that the dark band around the outside noted there is missing. However, the white areas increased from the outside to the middle both in number of patches and in size. The structure is entirely troostitic throughout, being very fine and unresolvable. There are to be seen a few small holes as previously noted.

Magnification 430 diameters.—The structure at this magnification is identical with that of specimen No. 3.

Magnification 950 diameters.—At this magnification the structure is identical with that of specimen No. 3. The granular nature of the troostite is plainly evident.

SPECIMEN NO. 5; TEST PIECE NO. 17; 1½ IN. DIAMETER.

(Fig. 15.)

This specimen is 0.50-per-cent-carbon chrome-vanadium steel. Heated to 1650° F. and quenched in oil; drawn at 500° F. for 60 minutes.

Magnification 90 diameters.—In general the structure of this specimen is quite similar to that of the two preceding ones, consisting of dark etching troostite and interspersed patches of white etching material, evidently ferrite

Around the outer edge of this specimen is a white etching band which might seem to indicate slight surface decarburization. Otherwise the whole surface of the specimen is very uniform. There are visible a few small holes.

Magnification 430 and 950 diameters.—These magnifications show practically identical structure with those of specimen No. 4. If anything, the white material, probably ferrite, is becoming more noticeable.

SPECIMEN NO. 6; TEST PIECE NO. 22; 1¾ IN. DIAMETER.

(Figs. 16 and 24.)

This specimen is 0.50-per-cent-carbon chrome-vanadium steel. Heated to 1650° F. and quenched in oil; drawn at 500° F. for 60 minutes.

Magnification 90 diameters.—At this magnification the structure of the specimen appears very similar to that of specimen No. 5. If anything, the whitish patches are larger and more numerous. The white etching band around the outside is again present in this specimen.

Magnification 430 diameters.—This magnification shows the whitish material to be gathered together in slightly larger patches. The granular nature of the troostite is plainly evident. In fact this constituent may almost be termed troosto-pearlitic.

NICKEL STEEL SERIES.

SPECIMEN NO. 7; TEST PIECE NO. 23; ½ IN. DIAMETER.

(Figs. 17 and 26.)

This specimen is 0.20-per-cent-carbon, 3.5-per-cent-nickel steel. Heated to 1550° F. and quenched in oil; not drawn.

Magnification 90 diameters.—This magnification shows a very beautiful, hardened structure over the whole specimen. There are a few small scattered holes. There is a slightly darker etching band around the outer edge of the material.

Magnification 430 diameters.—At this magnification the structure is shown to be beautiful and characteristic martensite, plainly showing the characteristic needle-like structure of this constituent. This martensite is quite characteristic of nickel steel, being larger grained than that of the chromium steels before described. The outer band seems to have lost some of the characteristics of martensite and to partake of a troosto-martensitic character.

Magnification 950 diameters.—At this magnification the needle-like triangular structure of nickel-steel martensite is plainly brought out. At this magnification the dark etching band at the outside is shown to be pure martensite.

SPECIMEN NO. 8; TEST PIECE NO. 28; 1¼ IN. DIAMETER.

(Fig. 18.)

This specimen is 0.20-per-cent-carbon, 3.5-per-cent-nickel steel. Heated to 1550° F. and quenched in oil; not drawn.

Magnification 90 diameters.—The specimen shows a martensitic structure which varies considerably from the outside to the middle. On the outside

is a thin skin which indicates decarburization. Inside of this is a dark band in which the white areas are less numerous. Proceeding toward the center the white areas become more and more numerous. Throughout the section are to be seen small holes.

Magnification 430 diameters.—This magnification shows a well-defined martensitic structure which varies slightly from the outside to the center.

Magnification 950 diameters.—This magnification shows a well-developed martensitic structure which varies but slightly from outside to center.

SPECIMEN NO. 9; TEST PIECE NO. 29; 1⅛ IN. DIAMETER.

(Fig. 19.)

This specimen is 0.20-per-cent-carbon, 3.5-per-cent-nickel steel. Heated to 1550° F. and quenched in oil; not drawn.

Magnification 90 diameters.—At this magnification the structure is unresolvable. It does not seem to be hardened. It is very finely crystalline The extreme outer edge seems to etch a little bit lighter than the rest of the specimen. Otherwise the structure is very uniform over the whole section.

Magnification 430 diameters.—At this magnification it is plainly seen that the structure is not all hardened, but consists of very fine grains of ferrite and what seems to be granular pearlite. The granular pearlite exists in small patches and outlines the ferrite grains. Toward the outer edge, the granular pearlite seems to be in much greater abundance and tends towards a pearlite-troostite structure. There seems to have been a slight decarburization around the extreme edge.

Magnification 950 diameters.—At this magnification the structure consists very plainly of ferrite grains outlined by granular pearlite, the granular pearlite also existing in small isolated patches. Along the outer edge of the piece the granular pearlite seems to be in greater abundance.

SPECIMEN NO. 10; TEST PIECE NO. 34; 1¼ IN. DIAMETER.

(Figs. 20 and 27.)

This specimen is 0.20-per-cent-carbon, 3.5-per-cent-nickel steel. Heated to 1550° F. and quenched in oil; not drawn.

Magnification 90 diameters.—At this magnification the structure is evidently not hardened and is very similar to that of specimen No. 9. The outer edge etches darker and seems to be somewhat more hardened. The specimen contains a good many small holes.

Magnification 430 diameters.—The structure at this magnification is very similar to that of the specimen No. 9, and consists of ferrite and what seems to be granular pearlite. The structure is very finely crystalline.

Magnification 950 diameters.—At this magnification the structure is very evidently ferrite and granular pearlite. The granular pearlite seems to be scattered somewhat more than in the preceding specimen and the ferrite grains seem to be somewhat smaller.

NOTE.—The bluish etching depressions or holes noted throughout this examination are not to be taken as evidences of non-homogeneity of the steel.

INFLUENCE OF MASS IN THE HEAT TREATMENT OF STEEL.

By K. W. Zimmerschied.

It is a matter of common knowledge that mass exercises considerable influence upon the properties of a piece of steel undergoing heat treatment, but concrete published data on this subject are very meager.

During the course of an investigation for other purposes, the opportunity of conducting a few experiments on this point offered itself, and the results are reported herein, since they exhibit very interesting and instructive phenomena. The scope of the work is narrowly defined, but the results are so promising that a considerably fuller program of experiments has been outlined for future development of the subject; the results of these experiments we hope will be valuable enough to report in full.

The material employed was of the "Mayari" or "Y" type, with low-nickel and chromium content; the analysis was as follows:

Carbon	0.37 per cent
Manganese	0.60 "
Phosphorus	0.010 "
Sulphur	0.030 "
Nickel	1.21 "
Chromium	0.58 "
Copper	0.10 "

Test bars were machined from the original 1½-in. rounds, as shown in Fig. 1. To take care of warpage and surface decarbonization during heat treatment, 0.040 in. was left on the diameter of the sections X and Z, to be ground off before pulling in the tensile machine. In order to have the heat treatment on sections X and Y the same, the latter was also turned to 1.169 in. in diameter, so that the physical properties of the steel throughout section X as a whole, and of that in the core (section Y) might be compared. Two such composite bars, marked M32 and T32, were subjected to heat treatment No. 2, and two others, marked T33 and T33*a*, to heat treatment No. 3, as shown in Table I.

After heat treating, each bar was then cut up into sections X, Y, and Z, as shown in Fig. 1. Each of these portions was then machined into a finished test piece of the diameter indicated in Table I, and pulled. Sections Y and Z were machined to the standard test piece of the Society of Automobile Engineers.

Detailed results of the tension tests of each section are given in Table I; a summary of the percentage relations of the averages, calculated both upon the basis of the lowest and of the highest figures obtained, are given in Table II. A consideration of these tabulations reveals some interesting data:

1. The results of duplicate tests are quite concordant except in the following cases: Tensile strengths on Y3 and Z3; elastic limits on Z2 and Z3; reductions of area on Y2, Z2, X3, Y3 and Z3; elongations on Y2 and Y3. All the averages, however, are very consistent.

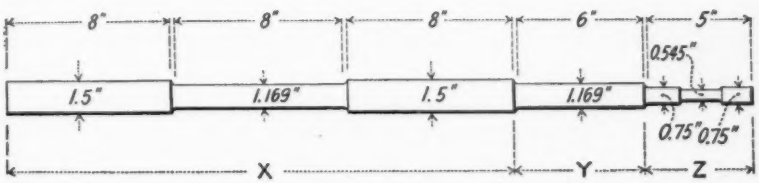


FIG. 1.—Test Bars.

2. The lower annealing temperature used in treatment No. 3 gives, as expected, consistently higher tensile strengths and elastic limits, together with lower reductions of area and elongations.

3. Given the same treatment, the smaller sections Z have considerably higher tensile strengths and elastic limits, while the reductions of area are not lower, as might be expected, but were even slightly higher. This we would explain by the relatively long period of annealing, 45 minutes, which has sufficed to toughen the thinner sections in a considerably greater degree than the thicker ones.

The elongations of sections X, Y, and Z are not strictly comparable, because the ratio between length and diameter was almost eight in the first series and four in the other two. This discrepancy will be corrected in future work.

4. The core of a $1\frac{1}{8}$-in. round bar (section Y), after this treatment, has distinctly better physical properties throughout than

TABLE I.—RESULTS OF TENSION TESTS.

Heat Treatment.	Mark.	Test Piece. Diameter Treated, in.	Test Piece. Diameter Pulled, in.	Tensile Strength, lb. per sq. in.	Elastic Limit, lb. per sq. in.	Reduction of Area, per cent.	Elongation, per cent.
	M3X2	1.169	1.1285	109 860	80 000	57.9	11.0[a]
	T3X2	.....	.....	110 800	82 000	54.7	12.0[a]
		Average..	.....	110 330	81 000	56.3	11.5[a]
TREATMENT No. 2.							
1. Heated 30 minutes at 1550° to 1575° F.	M3Y2	1.169	0.505	112 500	85 000	61.0	20.5
2. Quenched in oil.	T3Y2	.....	.....	117 000	85 000	56.0	17.5
3. Reheated 45 minutes at 1000° F.		Average..	.....	114 750	85 000	58.5	19.0
	M3Z2	0.545	0.505	140 900	117 500	60.5	17.0
	T3Z2	.....	.....	143 600	125 000	53.5	15.0
		Average..	.....	142 250	121 250	57.0	16.0
	T3X3	1.169	1.1285	119 000	84 000	46.1	10.1[a]
	T3X3a	.....	.....	118 400	89 000	56.1	11.5[a]
		Average..	.....	118 700	86 500	51.1	10.8[a]
TREATMENT No. 3.							
1. Heated 30 minutes at 1550° to 1575° F.	T3Y3	1.169	0.505	116 700	90 000	60.0	20.5
2. Quenched in oil.	T3Y3a	.....	.....	123 600	91 700	48.4	15.5
3. Reheated 45 minutes at 900° F.		Average..	.....	120 150	90 850	54.2	18.0
	T3Z3	0.545	0.505	145 300	125 000	56.5	14.0
	T3Z3a	.....	.....	160 000	140 000	47.0	12.5
		Average..	.....	152 650	132 500	51.7	13.2

[a] Elongation measured in 8-in. gage length; all others in 2-in. gage length.

TABLE II.—SUMMARY OF PERCENTAGE RELATIONS.

Heat Treatment.	Test Piece. Diameter Treated, in.	Test Piece. Diameter Tested, in.	Tensile Strength. Percentage of Lowest.	Tensile Strength. Percentage of Highest.	Elastic Limit. Percentage of Lowest.	Elastic Limit. Percentage of Highest.	Reduction of Area. Percentage of Lowest.	Reduction of Area. Percentage of Highest.	Elongation. Percentage of Lowest.	Elongation. Percentage of Highest.
	1.169	1.1285	100	77	100	67	100	96	...[a]	...[a]
No. 2	1.169	0.505	104	81	105	70	104	100	109	100
	0.545	0.505	129	100	150	100	102	97	100	85
	1.169	1.1285	100	78	100	65	100	94	...[a]	...[a]
No. 3	1.169	0.505	101	79	105	67	107	100	136	100
	0.545	0.505	129	100	153	100	101	95	100	73

[a] Elongation measured in 8-in. gage length; all others in 2-in. gage length.

those of the whole section. This condition is quite contrary to our expectation; the inside of a bar is generally supposed to have lower physical properties than the bar as a whole or than the outside. The following explanation of the results obtained is offered:

During quenching, the exterior of a bar is cooled more rapidly than the interior; and hence if untempered subsequently, the exterior portion would show higher tensile strengths and elastic limits with lower reductions of area and elongations than the center. On annealing, likewise, the exterior is again affected first and of course will be tempered more than the interior. By a proper adjustment of the time and temperature of this latter operation, then, we probably could manage to "draw back" merely the excess strength and brittleness of the outside of the bar and to balance its properties against those of the core. The above results show that the heating for 45 minutes has carried the tempering effect past this balance point, and that the exterior of the bar has been "drawn" to properties appreciably below those of the core.

5. Higher tensile strengths and elastic limits do not necessarily indicate the coexistence of lower reductions of area and elongations. In comparing the bars of section X with those of section Y, we find under both heat treatments that distinctly the reverse can happen. In the present case we would ascribe the cause to the difference in the quenching action of the oil upon the outside and upon the inside of the bar, respectively; the slower cooling to which the core has been subjected, due to its protection by the outside layers of metal, has left it in a considerably tougher state. If objections to comparing reductions on such different diameters of test bars are raised, we would refer to sections Y and Z. Here the tensile strengths and elastic limits have been increased about 25 and 50 per cent, respectively, while the reductions have been reduced only about 2 to 6 per cent.

In conclusion, the writer would reiterate that the fragmentary nature of this paper is fully appreciated. It is offered for whatever intrinsic value it may have, and in the hope that constructive criticism may be evoked which will help to guide us in future work along these lines.

[For discussion of this paper, see pp. 525–549.—ED.]

HEAT TREATMENT OF HYPO-EUTECTOID CARBON-STEEL CASTINGS.

By J. H. Hall.

This paper is submitted with the object of showing briefly the behavior of cast steels with carbon contents of less than the eutectoid ratio of 0.90 per cent, under varying conditions of heat treatment. The following definitions will be adopted, in order to give known values to terms commonly used somewhat loosely in technical papers.

1. *Slow Cooling.*—A slow cooling is such a rate of cooling that the steel shall cool from above Ac3 to black heat in not less than 50 minutes.

2. *Accelerated Cooling.*—An accelerated cooling is such a rate of cooling that more than 20 minutes and less than 50 minutes are required to cool the steel from above Ac3 to black heat.

3. *Rapid Cooling.*—A rapid cooling is such a rate of cooling that less than 20 minutes are required to cool the steel from above Ac3 to black heat.

4. *Ingotism.*—Ingotism is the coarse, crystalline structure of steel in the cast condition, and in hypo-eutectoid steels is indicated by the presence of primary ferrite resulting from the transformation of primary austenite *in situ*.

Two characteristic crystalline arrangements of the primary ferrite are found in hypo-eutectoid cast steels in the raw condition. The first is a network structure in which the ferrite is arranged in a network around meshes of pearlite, which is interlaced with secondary ferrite. The second is the Widmanstattian structure, in which the ferrite is in needles in a triangular, or "delta" arrangement. In any one steel there will generally be found both of these structures, to a certain extent; but some steels show the "delta" arrangement almost exclusively.

Professor Campbell, in an article in the Proceedings of this Society for 1909,[1] has shown that hypo-eutectoid cast steels

[1] Vol. IX, p. 370.

are completely refined by heating to 855° C. and cooling slowly; but that if sulphide of manganese is strongly segregated in the primary ferrite, traces of the latter will be found in the annealed steel. Professor Campbell's steel, shown in the raw condition in Fig. 5 of that article, shows the ferrite in the "delta" arrangement; and this steel, as shown in his Figs. 6, 7 and 8, is refined by heating to 840° C., and cooling slowly. The structure of the refined steel is, however, quite coarse.

In an article in the Proceedings for 1908[1], Professors Howe and Campbell and Mr. Koken showed that the ingotism of a cast steel was not effaced by 32 hours heating at 840° C.; patches of primary austenite being left in the steel after slow cooling.

It is the experience of the author that in cast steel, heated above Ac3 and cooled slowly, ferrite is reprecipitated more or less upon the lines originally occupied by it in the raw steel; and that if the network arrangement is found in the raw steel, traces of network will be seen in the refined steel; while if the rarer "delta" arrangement of the primary ferrite is found in the raw steel, few traces of ingotism will occur in the refined steel. This may perhaps be owing to the fact that manganese sulphide segregates more markedly in steel possessing the network arrangement of the primary ferrite.

Though the fineness of the ingot structure of cast steel varies with the size of the casting, the center of a very large casting showing extremely coarse patches of ferrite, it is nevertheless the author's experience that the temperature necessary to efface this ingotism is practically independent of the coarseness of the structure; and that at a given temperature, for instance 850° C., the time necessary for the refining to take place, counted from the moment when the steel has reached that temperature throughout its mass, is the same for both large and small castings. Though 850° is high enough to refine the ingot structure of hypo-eutectoid cast steel, yet 900° will refine it more rapidly and hence was adopted as the standard refining temperature for the work which is to be described.

Fig. 1 shows the microstructure of a cast steel annealed for two hours at 900° C., cooled slowly to 800°, and quenched in

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[1] Vol. VIII, p. 185.

water; Fig. 2 shows a similar steel, heated to the same temperature for the same length of time, cooled slowly to 750°, and quenched in water. Fig. 1 shows very fine sorbite (or martensite), while Fig. 2 has the typical structure of steel heated above Ac3 and cooled slowly. The strongly marked patches of ferrite occupying the outlines of the primary ferrite network are strikingly shown in Fig. 2.

Fig. 3 shows a similar steel heated to 900° C. for 3 hours and cooled very slowly; in this case the cooling from 900° to 600° occupied 6 hours. A general family resemblance is seen between Figs. 2 and 3, with the difference that in Fig. 3 the coarse ferrite occurs in wide masses; and rather more ferrite in finer particles occurs. The steel of Fig. 2, quenched from above Ar1, does not of course show as complete a separation of ferrite as Fig. 3.

Fig. 4 shows a similar steel, heated to 900° C. for 3 hours, and cooled in air in about 10 minutes. The fine network structure is characteristic.

In Fig. 5 is shown the structure of a similar steel heated to 900° for one hour, and cooled to black in 40 minutes, or at an accelerated rate. There is a close resemblance between Figs. 4 and 5, but Fig. 5 shows a somewhat coarser structure, owing to the slower cooling.

Fig. 6 shows a similar steel heated to 900° C. for $2\frac{1}{2}$ hours, cooled slowly to 800° and quenched, then reheated to 700° and quenched. Comparing Figs. 1 and 6, we see that in Fig. 6 the ground mass is an extremely fine mixture of ferrite and pearlite (or sorbite); but masses of primary ferrite have been formed, showing the characteristic arrangement of primary ferrite in the network form.

Fig. 7 shows a similar steel heated to 900° C. for $2\frac{1}{2}$ hours and cooled in air, then reheated to 700° for one hour and cooled slowly. Comparing Fig. 7 with Fig. 4, we see that their structures are almost exactly alike, except that in Fig. 7 the ferrite is slightly coarser.

In Fig. 8 is shown a similar steel heated to 900° C. for 2 hours and air-cooled, then reheated to 750° for one hour and cooled slowly. Comparing this with Fig. 7 and Fig. 4, it will be seen that the ground mass of Fig. 8 resembles Fig. 7 closely,

the ferrite being naturally a little coarser; but in addition there are the same patches of ferrite in the network arrangement of the original network structure that obtain in Fig. 6.

It is clear from these examples that the cast steel has a strong tendency to reprecipitation of ferrite in heavy masses along the lines of the original ingot structure; that this tendency can be repressed by accelerated or rapid cooling; and that if so repressed, upon again heating above Ar1 the ferrite tends strongly to the same coarse recrystallization. In this connection, the author wishes to state that the photographs show only a few of several hundred samples of steel treated in the course of this research, all of which showed the same tendency to crystallization of coarse ferrite under the same conditions; some less strongly than those shown, some more so.

One somewhat unexpected result shown in these photographs is that in reheating a quenched steel, coarse ferrite appears upon a very short heating at 700° C., while in reheating an air-cooled steel, even after one hour at 700°, no such reprecipitation of ferrite occurs. This appeared so inherently improbable that the greatest pains were taken to prove the fact, two bars of the same steel being heated side by side in the same furnace to 900°, one quenched and one cooled in air, then reheated side by side in the same furnace to 700°, and cooled slowly together. This experiment was twice repeated on two different steels, and twice confirmed the fact.

In order to show that steels quite low in sulphur exhibit the same characteristic behavior in annealing, Fig. 9 (an electric-furnace steel) is added to this collection. This steel was heated to 900° C. for 4 hours and cooled in air, then reheated to 760° for 2 hours and slowly cooled. Comparison of Figs. 9 and 8 shows that this steel, comparatively low in sulphur, exhibits the same traces of primary austenite after this treatment.

Clearly, then, in order to produce a truly fine microstructure in cast steels, it is necessary to restrain or suppress the tendency to coarse crystallization of the ferrite by accelerated or rapid cooling, since slow cooling as defined in this paper results in coarse structure. The effect of rapid cooling being to harden the steel very considerably and at the same time produce harmful stresses in castings of uneven section, a second heating to soften

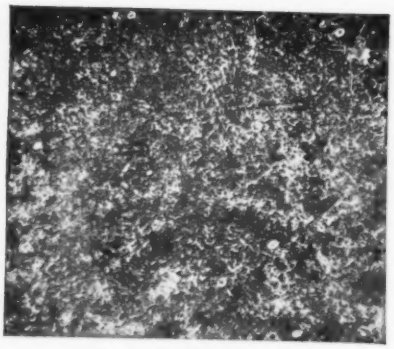


FIG. 1.

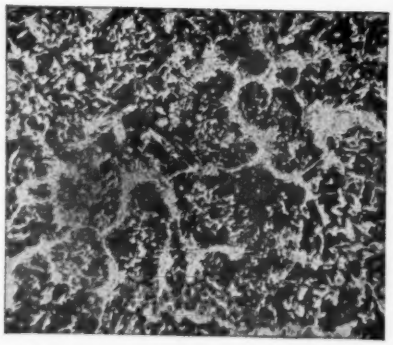


FIG. 2.

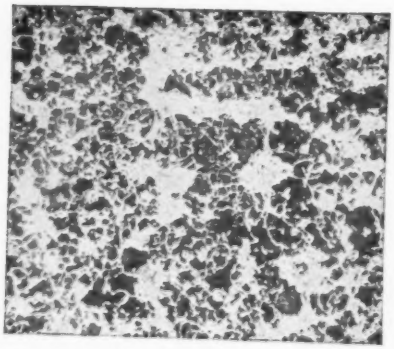


FIG. 3.

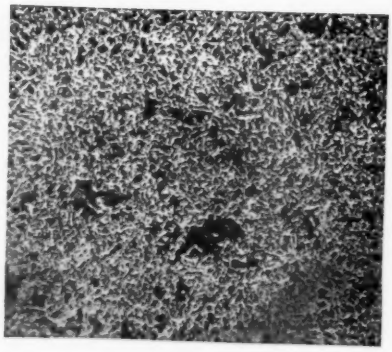


FIG. 4.

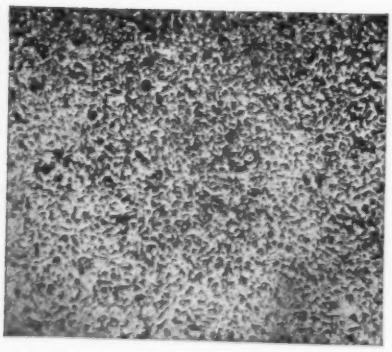


FIG. 5.

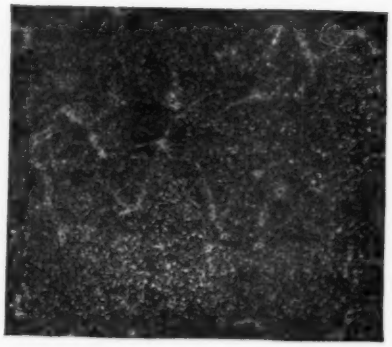


FIG. 6.

MAGNIFICATION, × 60.

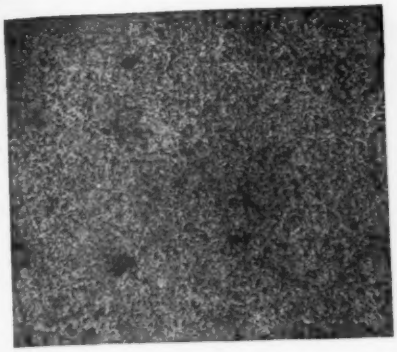


FIG. 7.

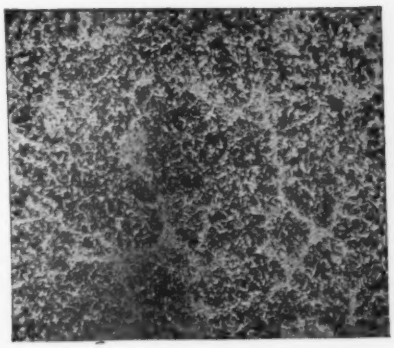


FIG. 8.

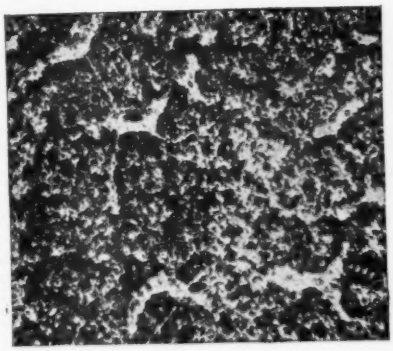


FIG. 9.



FIG. 10.

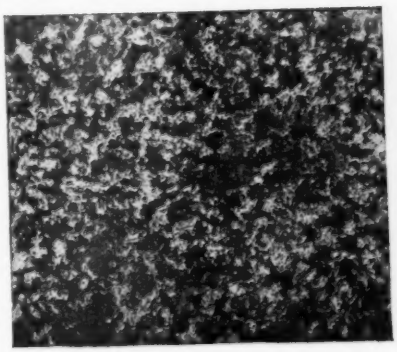


FIG. 11.

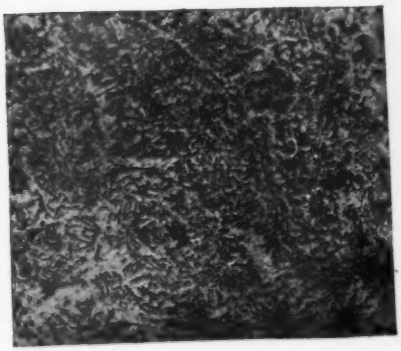


FIG. 12.

MAGNIFICATION, × 60.

the steel and relieve the stresses is necessary; but this heating must not exceed 680° C. for quenched steel and 720° for air-cooled steel, or a crystallization of ferrite in coarse masses will take place.

Fig. 10 shows a soft steel heated to 900° C. for 5 hours and quenched, then reheated to from 650° to 680° for 6½ hours and cooled in air. The physical properties of this steel are as follows:

TENSILE PROPERTIES.	
Tensile strength, lb. per sq. in.	91 900
Elastic limit, lb. per sq. in.	71 650
Elongation in 2 in., per cent	20.37
Reduction of area, per cent	50.25
Fracture	Silky
BEND PROPERTIES.	
Specimen 1 by ½ in. bent 180 deg. around a 1-in. mandrel.	
FREMONT TEST	21.0 kgm.

In order to show the influence of microstructure upon the physical properties of the steel, Figs. 11 and 12 are given. These are the microstructures of two small castings of about the same carbon content as the steel shown in Fig. 10, which have been annealed by heating and slow cooling, and exhibit the characteristic coarse crystallization of cast steel so treated. These castings were not large enough to cut tension specimens from them, but Fremont tests from them give for No. 11, 5.0 kgm., and for No. 12, 7.0 kgm. The casting whose microstructure is shown in Fig. 12 was then cut in two, one-half set aside for test, and one-half treated as follows: Heated to 900° C. for 4 hours and quenched in water, reheated to 680° for 8 hours and cooled in air. The two halves were then tested under a drop of about a 500-lb. falling weight, with the result that the annealed half (Fig. 12) broke into three pieces with one blow of the drop from a height of 4 ft.; while the heat-treated half was unbroken after one blow from 4 ft., one blow from 5 ft., one from 6 ft., one from 7 ft., and two from 8 ft., six blows in all. The two halves of the casting after test are shown in Fig. 13(*a*), and the unbroken heat-treated half is shown in back view in Fig. 13(*b*).

In a paper already submitted to this Society[1] the author has

[1] Presented as a contribution to the discussion of shock tests at the Sixth Congress of the International Association for Testing Materials, New York City, 1912.

shown the great variations that occur in the value of the Fremont test from the outside and the inside of coupons of cast steel; but the test just cited will show that the indications of this test can be taken nearly at their face value in the case of castings of light section.

That even steel very low in carbon is considerably improved,



(*a*) (*b*)

FIG. 13.

especially in resistance to shock, by quenching and reheating, is shown by the following tests upon steel of 0.10 per cent carbon, low in silicon and manganese. This steel is shown in the cast

TABLE I.—RESULTS OF TESTS OF 0.10-PER CENT CARBON STEEL.

Figure No.	Treatment.	Tensile Strength, lb. per sq. in.	Elastic Limit, lb. per sq. in.	Elongation in 2 in., per cent.	Reduction of Area, per cent.	Fracture.	Degrees Bend of 1 by 4-in. Specimen around 1-in. Mandrel.	Fremont Test, kgm.
14	None.....	50 020	23 930	35.2	47.85	coarse crystalline	50	2.5
15	900° for 3 hr., cooled in 40 min.....	55 390	28 750	38.5	67.0	silky cup	180	20.0
16	900° for 3 hr., cooled slowly.....	.....	.....	.....	.....	.....	45 (blow hole)	10.5
17	900° for 3 hr., quenched.....	.....	.....	.....	.....	.....	180	27.5
18	900° for 3 hr., air-cooled; 710° for 6 hr., air-cooled..	56 450	32 950	39.25	65.2	silky cup	180	17.5
19	900° for 3 hr., quenched; 680° for 8 hr., air-cooled.....	53 200	27 100	34.95	60.4	silky cup	180	25.0

condition in Fig. 14; in Fig. 15, after heating to 900° C., for 3 hours and cooling to black in 40 minutes; in Fig. 16, after heating to 900° for 3 hours and cooling slowly; in Fig. 17, after heating to 900° for 3 hours and quenching in water; in Fig. 18, after heating to 900° for 3 hours and cooling in air, then reheating to 710° for 6 hours and cooling in air; and in Fig. 19, after heating



FIG. 14.



FIG. 15.

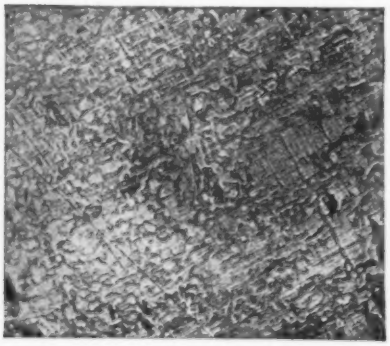


FIG. 16.

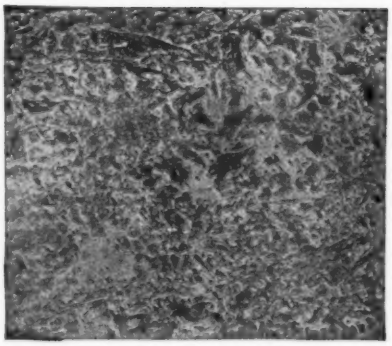


FIG. 17.

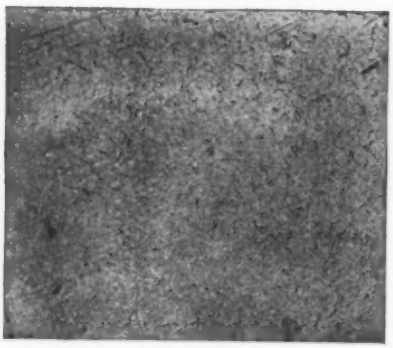


FIG. 18.



FIG. 19.

MAGNIFICATION, × 60.

to 900° for 3 hours and quenching in water, then reheating to 680° for 8 hours and cooling in air. These coupons were all cast on one casting. The physical properties of these bars, as far as they could be obtained, are given in Table I.

A notable improvement in the physical properties of this

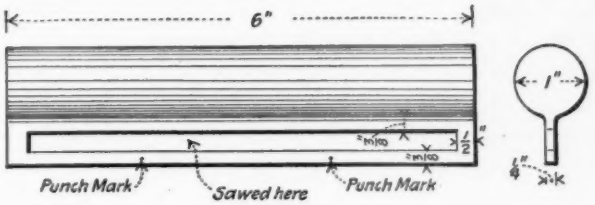


FIG. 20.

steel is made by the heat treatment, and this is most strikingly shown in the Fremont test, which from almost nothing in the raw steel, rises to 25.0 and 27.5 kgm. in the specimens that have been quenched. The air-cooled and reheated sample and the sample cooled at an accelerated rate, show Fremont values of 17.5

TABLE II.—ANALYSES OF STEELS.

(VALUES ARE PERCENTAGES.)

Figure No.	Carbon.	Silicon.	Manganese.	Sulphur.	Phosphorus.
1	0.42	0.51	0.60	.....	.....
2	0.39	0.48	0.47	.....	.....
3	0.41	0.45	0.51	.....	.....
4	0.43	0.49	0.60	.....	.....
5	0.41	0.52	0.68	.....	.....
6	0.39	0.41	0.55	.....	.....
7	0.35	0.42	0.65	.....	.....
8	0.35	0.42	0.65	.....	.....
9	0.59	0.14	0.72	0.023	0.017
10	0.21	.....	1.17	.....	.....
11	0.18	0.41	0.93	0.065	0.052
12	0.20	0.45	1.02	0.057	0.049
14 to 19	0.10	0.19	0.23	.....	.....

and 20.0 kgm., while the annealed and slowly cooled steel gives but 10.5 kgm.

By means of test bars such as those illustrated in Fig. 20, which were used for rough measurements of stress by measuring the distance between punch marks in the lighter section before and after sawing through this part with a hack saw, determinations of stresses in the cast steel after various treatments were

made. It was found that the raw steel, or the steel heated to 900° C. and cooled in air, water or oil, was in a state of serious stress; that the slowly cooled steel was quite free from stresses; and that the stress in the steel cooled in 40 minutes from 900°, or cooled in air from 680° and 700°, was too slight to be measured.

All microphotographs are at a magnification of 60 diameters. All samples were heated in an electric resistance muffle furnace, the temperatures being measured with a Le Chatelier pyrometer. The steels, with the exception of the electric-furnace steel and the two castings, Figs. 11 and 12 (whose origin is unknown), are all baby-Bessemer steels. Complete analyses of the samples are unfortunately not available, but it can be stated that the phosphorus and sulphur of all of them lie between about 0.04 and 0.07 per cent, averaging a little over 0.05 per cent. The analyses so far as available are given in Table II.

[For discussion of this paper, see pp. 525–549.—ED.]

GENERAL DISCUSSION ON HEAT TREATMENT OF STEEL.[1]

MR. HENRY D. HIBBARD.—The question of the influence of mass on heat treatment of steel is really one phase of the underlying question as to the effect of rate of cooling on heated steel; that is, what rate of cooling in degrees per second is necessary to produce a given hardening effect for a given steel; or to express it otherwise, what is the result in hardening effect—or in the formation of metarals, to use Howe's term—of a given rate of cooling? This question has never been taken up, so far as I know. Mr. Hibbard.

The mass of a heat-treated steel article determines very greatly the rate at which it loses heat in quenching; the more massive the article the slower the rate of cooling as a whole. Then there is the question as to the rate of cooling of the surface and the layers of steel underlying at increasing depths as influenced by the mass of steel still deeper from the cooling surface. If all this were known we would have papers on the effect of cooling a given steel at a given rate instead of those describing the influence of mass, cooling fluid, conditions of quenching, etc.

It may be that there is a critical rate of cooling which must be applied to a given steel to give it the maximum hardness it is capable of assuming, but that, of course, is at present a matter of conjecture. The curve for each grade of steel obtained by plotting the degree of hardness imparted by each rate of cooling from a given temperature would be most valuable.

In practice the slower rate of cooling of a more massive piece of steel is counteracted to some extent by keeping the cooling fluid in motion so that it will more rapidly extract the heat,—as in the hardening of large dies and armor plate,—but even with all such measures a limit of thickness which may be usefully hardened is quickly reached. Maximum hardness

[1] Joint Discussion of the preceding three papers by Mr. J. H. Nead, Mr. K. W. Zimmerscheid and Mr. J. H. Hall.—ED.

Mr. Hibbard. can only exist in a shallow zone extending in from the cooling surface. The effect of the cooling decreases as the depth from the surface increases, but whether in proportion to the depth is probably not known. All this calls for determination.

It would be very instructive if the series of tests given in the papers of Messrs. Nead and Zimmerschied could be extended in both directions to the maximum properties on the one side, and the minimum on the other. As for the maximum tensile strength, it would be especially interesting to compare it with the maximum given to steel in the wire-drawing process, by which a tensile strength of over 500,000 lb. per sq. in. has been obtained.

Mr. Devries. MR. R. P. DEVRIES.—The matter presented in the paper dealing with effect of section on heat treatment is of great interest. Although the heat-treated specimens with which I have been working for some time are practically all of the same section, the geometric form of the section plays an important part.

In Mr. Zimmerschied's paper some explanations of the results obtained are offered on the basis that the separate effects of the quenching and drawing of the heat-treated specimen can be differentiated. Since heat treatment of steel involves the two operations above mentioned, it would appear that caution should be exercised in drawing conclusions unless specimens on duplicates are tested in the treated state both before and after drawing the temper.

So far as it has been possible to note, neither of the two papers have mentioned the effect of the temperature of the quenching bath. I would therefore ask whether it is possible to duplicate results in heat-treating steel when no attempt is made to hold the temperature of the bath constant. This was found to be an important point in the heat treatment of high-carbon steel. Some of the irregularities found in specimens heat-treated in the laboratory of the Pennsylvania Railroad Co. were ascribed to causes other than the quenching bath. Specimens heat-treated at the Bureau of Standards showed that these irregularities persisted, and it is believed that failure to keep the temperature of the quenching bath constant is responsible for the differences in physical qualities observed.

Mr. Webster.

MR. W. R. WEBSTER.—I think that as a matter of record it might be well to call attention to the results of some tests that were made by Mr. A. L. Colby some years ago on 8-in. lengths and 2-in. specimens of different diameters to bring out the difference in results due to the difference in length.

Mr. Acker.

MR. E. O'C. ACKER.—I think Mr. Zimmerschied has drawn the wrong conclusion from the results of these different bars. We find ordinarily that the tensile strength of an 8-in. bar is about 2000 to 3000 lb. per sq. in. less than that of a 2-in. bar of the same material. A curve was published a good many years ago on this subject, I think in 1885, in a paper by Naval Constructor Gatewood. It seems to be lost sight of that a change in ratio of length to diameter changes the tensile strength as well as the elongation, and if the necessary corrections were applied to Mr. Zimmerschied's results, he would find, I think, that the core of his metal was not stronger than the outside.

Mr. Nead.

MR. J. H. NEAD.—In reply to Mr. Devries, I would say that in our experiments, the temperature of the bath was kept constant between 65° and 75° F. No experiments were carried out at that time as to the effect of the temperature of the quenching bath.

Mr. Zimmerschied.

MR. K. W. ZIMMERSCHIED.—Replying to Mr. Hibbard, I believe that keeping a piece of steel in motion has the principal effect of brushing the film of vapor off the surface more rapidly and hence of keeping the steel more continuously in contact with the quenching liquid. A variation of a few degrees in the temperature of that liquid, so long as this temperature is well below the boiling point, does not seem to make much difference in steel as low in carbon as these samples.

Mr. Devries' point is well taken; from a theoretical viewpoint the introduction of more than one variable at a time is highly undesirable. The practical difficulties in testing steel which has been simply hardened, however, are very great. Uncertain and unequal internal stresses give rise to discordant results between duplicates, and it is extremely difficult to measure anything but the maximum strength, especially on small test pieces. By using two drawing temperatures we purposed to find out if the mass effect would be concordant throughout, and I think that the percentage table shows that it is. The

Mr. Zimmerschied.

temperature of the quenching bath was about 85° F. and the volume about 200 gallons.

With regard to ratio of length to diameter, it is noted in the paper that this will be corrected in future work. We shall adopt a gage length four times the diameter; this ratio holds in the small standard test piece. The pulling speed was low in all cases.

Mr. Onderdonk.

MR. J. R. ONDERDONK.—I wish to correct the impression that the speed of testing from 2 in. up to 6 in. per minute does not make any material difference in the test. I think the tests upon which this conclusion presented to the Society is based, were made on low-carbon steels and 8-in. test pieces. When we are dealing with high-carbon steel in short 2-in. test pieces, we find that the pulling speed makes considerable difference.

In regard to heat-treated steel, I cannot add much from the laboratory side, but in its use I think we are liable to be misled by the results we get by not running the service tests long enough, especially on material that is subject to abrasion. When we first put it in service, the heat-treated material appears to give us very good results, and we get possibly twice the service as from steel that is not heat-treated; but when the outer material wears off or is turned off, the material commences to wear much more rapidly than steel that is not heat-treated, so that the total result from a material that is worn or turned off is found to be very little greater, if any, than that from the ordinary steel without heat treatment. Therefore, in getting service results in that way, I think the tests should be continued until the piece is finally worn out under the service for which it is intended.

Take a tire, for instance; the first mileage for a tire that has been heat-treated is possibly twice that for an ordinary carbon tire without heat treatment. That tire is then turned off and put in service again. The second mileage for the heat-treated tire is not as great as the second mileage for a non-heat-treated steel tire. Turn that tire again and put it in service for the third time, and the total mileage of the three services is not appreciably greater for the heat-treated steel tire than for the ordinary carbon-steel tire.

MR. A. A. STEVENSON.—I feel that the effect of mass on the results from heat-treated material has not been fully appreciated in some of our committee work. The basis of our heat-treated specifications to-day were the specifications adopted by the Society in 1902. These specifications called for a certain elastic limit, elongation and reduction for pieces 6 in. in diameter, or having a thickness of 6 in. At that time hollow-bored axles were not in use to any extent, if at all. The thickness of 6 in. covered by the original specifications would be such as would be found in a gun ring where there would be a hole of some size, and the effect of treatment would be practically the same from the inside out as from the outside in. **Mr. Stevenson.**

One of the first specifications for heat-treated forgings was issued by Mr. Doyle of the Interborough. The axles were of small size as compared with the locomotive driving axles. The physical requirements were the same as in the Society's specification of 1902. Later on the steam railroads took up the question of heat-treated axles and forgings, and the tendency has been to call for the same physical requirements as referred to above.

As a matter of comparison, take a 6-in. solid axle, 72 in. long, and it will be found that the radiating surface amounts to practically $2\frac{1}{2}$ sq. in. per pound of metal. Then take a 13-in. axle with a 3-in. hole, 72 in. long, for which the radiating surface is about $1\frac{1}{2}$ sq. in. per pound of metal. There is no doubt that the effect of the radiating surface in the 3-in. hole is not as great as the effect of the radiating surface on the outside, per square inch of surface.

The results given in the paper under discussion are interesting, but I believe experiments carried out on larger-size sections 12, 13 and 14 in. in diameter would be of even greater interest.

MR. ROBERT JOB.—I have been very much interested in the discussion and realize very fully indeed the importance of the effect of heat treatment upon steel. We have had it brought to our attention recently in connection with some engineering work, particularly in connection with the life and general service which is given by forgings. In their manufacture we have, at different times, found a very wide difference in the properties of steel, and equally so in the service. We have found also that when carefully manufactured, with careful heat treatment and **Mr. Job.**

Mr. Job. with a consequent increase in the tensile strength, reduction of area and elongation, the service has kept pace with the increased properties. In other words, as a result of the effective heat treatment which had been given by the mills, decidedly better results have been obtained as would be expected. The whole subject unquestionably needs the fullest possible study, particularly in view of the large masses of metal which are treated, as has been brought out in the papers before us. It is very evident that in such cases, very different treatment is necessary from that required for the smaller masses, and on that account we ought to be very careful about drawing inferences from the results obtained upon smaller pieces.

Mr. Capp. MR. J. A. CAPP.—I had not intended to say anything, but there is one point in connection with the consideration of the real physical properties of a relatively large heat-treated forging which is perhaps worth mentioning. Of course the test piece in such a big forging has to be relatively small. The prolongation from which the test piece is to be cut is as short as it can be to permit getting out the test piece. We have had it shown to us that there is an influence of size of section in the case of a round or cylindrical forging. Equally then there must be an influence of distance in from the end of the forging. Our test piece is taken within a length of about four inches from the end. If the forging is, say 7 or 8 in. in diameter, would you get the same results if a test piece were taken at the next four inches or still further from the end? If our test piece is taken too near the end, we may get a higher result and probably would get a higher result, than if it were taken further from the end. Therefore, does the test piece as it is taken, represent accurately the properties of the forging as it is used in service, and if it does not, are not the results misleading and may not such misleading results account for some of the failures that have been found with heat-treated forgings?

In fact, I have had it recently called to my attention that in certain heat-treated forgings the fracture occurred always at the end of the test piece which was farthest from the end surface of the forging from which it was taken. In other words, the end nearer the surface was harder and stronger than the inner end of the test piece. Undoubtedly this was due to the influence of the mass of metal.

MR. J. S. UNGER.—I am afraid that Mr. Zimmerschied is attempting to draw conclusions from insufficient data. There is not enough difference in mass between a specimen $1\frac{1}{8}$ in. in diameter and another $\frac{1}{2}$ in. in diameter to show any very great difference in the physical properties. We must admit that a better comparison could be made between a 3-in. and a $\frac{3}{8}$-in. round rod when rolled from the same heat of steel, and that the effect of work and cooling would be very evident. Mr. Unger.

Duplicates tests should check within 1500 to 2000 lb. when of the same size and tested under the same conditions. By referring to Table I of Mr. Zimmerschied's paper and comparing the tensile strengths of the 1.1285-in. specimens, we find that they check in both cases, but the results on the 0.505-in. specimens do not check in any case, as we find a variation of from 3000 lb. as a minimum to 15,000 lb. as a maximum. A comparison of the averages of such results should not be considered, as they vary too much within themselves. When the effect of different diameters, lengths, and pulling speeds are taken into consideration, the results are not truly comparable, and will account for the greater part of the differences shown, without attributing these differences to the influence of mass.

Those who have had experience with pieces from 6 to 18 in. in diameter know that similar specimens taken out of the center and at the edge will not show the same results, when it is positively known that the steel is of uniform composition throughout. The practice of some manufacturers of leaving a small prolongation about $1\frac{1}{2}$ in. in diameter on the end of a large forging for test has been discontinued, and test specimens from the full-size forging are required, as it is recognized that the small prolongation does not represent the condition of the forging after heat treatment.

The explanation given by Mr. Zimmerschied that the outside of the specimens was affected first, and consequently drawn back a little farther than the core, may be true; but if the heating were forced rapidly enough to make a difference in a $1\frac{1}{8}$-in. specimen, the heat treatment was very poorly done. In other words, the temperature of the furnace was so high that before the heat could be conducted from the outside to the core, the outside was overheated.

Mr. Unger. I believe that in order to show the effect of mass, the comparison should be made between a ½-in. bar and a 10-in. bar in which all tests are made under the same conditions. If a large number of such tests were made, it might be possible to draw some conclusions. The comparison shown between 1.1285 and 0.505-in. specimens and from two tests of each kind, with several variables in testing, do not seem to give reliable comparative results.

Mr. Nead. MR. NEAD.—The discussion this evening has been mainly in connection with the effect of heat treatment on forgings of very large size, such as railway car axles, steel tires, etc., of which my paper makes no pretense of treating.

There have been no questions nor any discussion concerning the subject matter of the paper itself, which has to do only with such sections of such sizes as are used in automobile construction.

The Chairman. VICE-PRESIDENT A. W. GIBBS (*in the chair*).—Nobody doubts the success the automobile people have had in the treatment of steel; the wonderful work those machines are doing is sufficient proof of that. But we do want to see how that success can be extended to the larger sizes.

Mr. Zimmerschied. MR. ZIMMERSCHIED.—There is undoubted need for extension of this field of work, but such extension is outside of our immediate province. The largest section we treat is, in special cases, 4 in. round, and the very great majority of parts do not exceed 1½ in. as the minimum dimension of the maximum section.

With respect to Mr. Unger's statement concerning the differences to be expected between bars rolled to 3 in. and to ⅜ in. in diameter respectively, we certainly concur in his opinion. It has, however, nothing to do with the present case, since it is plainly stated that our bars were all originally rolled to the same diameter from end to end, and machined afterwards to the form shown.

With respect to the heat-treatment practice, we should have stated more fully the experimental conditions. The furnace was gas-fired, with a hearth 60 by 40 in. The temperature was controlled by an accurately calibrated pyrometer and was uniform from end to end. For all operations the temperature of the furnace was brought to the point desired, the

steel introduced, and the temperature held after regaining its original degree for the time indicated in the tables. In so large a furnace the temperature depression, due to the introduction of so small an amount of steel, was relatively inconsiderable. Mr. Zimmerschied.

With regard to the insufficient number of tests, we have stated that we realized this point but that the tests were reported in the hope of evoking just the kind of discussion which has been aroused. In conclusion, we wish to express our gratification at the discussion that has been created by these papers and to assure those who may be interested that the work will be pursued more at length.

MR. E. F. KENNEY.—In reference to one statement made by Mr. Zimmerschied: the true explanation for the lower strength in the larger sections of these bars has, I think, not been brought out yet. I think it is due to the fact, that as a piece of steel cools more slowly, there is a greater possibility of the segregation of some of the weaker constituents. This is shown by the illustrations given in Mr. Hall's paper on Heat Treatment of Hypo-Eutectoid Carbon-Steel Castings. In considering ordinary carbon steels, when we remember that ferrite has a tensile strength of 40,000 lb., whereas pearlite runs to upwards of 120,000 lb., we can understand why ferrite in masses will result in much weaker material than if that material is so broken up that the fracture has to take place, not only through the weaker constituent, but also through the pearlite, which is much higher in strength. Mr. Kenney.

There is one other point to which I should like to call attention. In Mr. Hall's paper, attention was called to the fact that a very much finer and better structure which would resist shock was obtained by quicker cooling; in fact, the author went to the extent of speaking of quenched castings. That is very true of the structure, but this procedure for most castings is not practical. In a practical sense, we must remember that while we get an excellent microstructure by rapid cooling, we may induce shrinkage strains in the castings which will ruin them as a whole.

MR. HUGH P. TIEMANN (*by letter*).—In connection with the papers of Messrs. Nead and Zimmerschied, I believe a brief consideration of certain of the general principles involved in Mr. Tiemann.

Mr. Tiemann. heat treatment will be of assistance in arriving at a better understanding of the effect which mass introduces into the problem.

In these papers "heat treatment" is understood to mean quenching and tempering—the term "drawing back" being commonly used to designate the latter operation. It might be well to point out that the commercial meaning of heat treatment is improperly restricted to quenching and tempering, and hence does not include annealing, which is always specified as such. It is desirable to have this point straightened out with the trade.

The most comprehensive definition of heat treatment which has so far occurred to me is the following:

Heat treatment is the change, or the series of changes, in temperature, and also in some cases the rate of change from one temperature to another, brought about to secure certain desired conditions or properties in a metal or an alloy.

Quenching, as generally understood, is simply a means to secure the rapid cooling (that is, the speedy removal of heat) of a heated body by immersing it in some liquid. This term is sometimes also applied to air cooling.

The object of quenching is to preserve more or less perfectly in the cold state the condition in which the material existed (was in equilibrium) at the temperature from which it was quenched. The condition above the critical point A3 is a solid solution of carbon in gamma iron, and its retention in the cold state results in a marked increase in the hardness and strength over what is normal in slowly cooled steel, depending upon the composition, more especially the carbon content. As experiments generally recorded have had to do with pieces of relatively small cross-section, cooling sufficiently rapid to permit of this condition being closely approximated has been possible.

The tempering or drawing back of quenched material, by permitting the transformation of part or all of the solid solution into pearlite and the excess constituent (if any), results in an increase in ductility and toughness, and a corresponding decrease in hardness and strength which are proportionate to the temperature to which the material is reheated below the lower critical point.

Mr. Tiemann.

The next point to consider is the effect of slow cooling and its bearing on the quenching temperature. For the purpose of this discussion it will be sufficient to consider only hypo-eutectoid steels—those which contain not over about 0.85 per cent carbon.[1] It may be mentioned that during the cooling from the upper to the lower critical point ferrite is continuously thrown out of (solid) solution, whereby the solution remaining is enriched in carbon until of eutectoid composition, which is then transformed into pearlite when the lower critical point has been passed.

The ferrite which is thrown out of the solution will principally be found in the form of an envelope around the grains of pearlite, the size of these grains corresponding more or less closely to the maximum temperature above the upper critical point from which the pieces were cooled.[2] When the material is again heated, this envelope is again dissolved between the lower and the upper critical points, the solution being complete only after the latter has been passed.

If therefore the treating temperature is not above the upper critical point, or the heating has been too rapid to permit of this solution, (*a*) the original grain size will not have been thoroughly broken up (refined), and (*b*) the effect of the relatively soft, weak and ductile ferrite upon the physical properties of the material will be apparent.

While there is a certain retardation or lag during the transformation from one condition to another, complete retention of the gamma condition in the cold state can only be secured by extremely rapid cooling, being dependent also upon the composition. To secure the requisite rate of cooling the cross-section must be small.

The employment of a quenching medium, such as water, is to obtain more rapid cooling than would result from ordinary cooling in air, but the nature of the medium *per se* does not confer any peculiar effect; for example, a fine wire will be cooled much more rapidly by simple exposure to air than will a large

[1] For a more complete exposition of the subject, reference should be made to a paper by H. M. Howe, entitled "Life History of Network and Ferrite Grains in Carbon Steel"; *Proceedings*, Am. Soc. Test. Mats., Vol. XI, p. 262 (1911).

[2] H. M. Howe, "Iron, Steel and Other Alloys," Second Edition, p. 245 *et seq.*

Mr. Tiemann.

piece of the same composition plunged in iced brine, the resulting physical properties in each case being directly proportional to the rate of cooling.

The properties of a piece of steel are dependent primarily upon the condition in which the carbon exists. In the solid solution (austenite), as in a liquid solution, the distribution of the solute (carbon or carbide) in the solvent (iron) is complete, and individual particles cannot be detected even under the highest magnifications. When the residual solid solution is transformed in passing the lower critical point, the resultant pearlite may be very fine or very coarse, depending upon the rate of cooling below this point. The coarsening of the pearlite due to very slow cooling is a segregation of its components, ferrite and cementite, which is not usually considered as such, as it cannot be detected by ordinary chemical analysis, although under the microscope it is readily apparent.

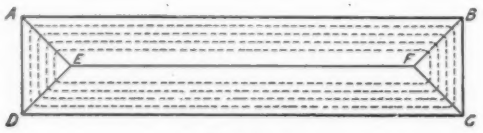


FIG. 1.

Rapid cooling therefore tends to preserve the fine distribution of the carbon. At the relatively low temperatures used for tempering, the pearlite present has but little opportunity to become coarsened owing to the viscosity of the metal which will not permit of ready rearrangement of the molecules. It is for this reason that with material of the same size and composition a much higher relation between ductility and strength can be obtained by quenching and tempering than by simple annealing.

Under similar conditions the rate of heating and cooling of a large section is much less than for a small section, as a greater distance must be traversed in the absorption or the dissipation of the heat by the body, the rate progressively decreasing as the temperature of the body approaches that of the source of heat or refrigeration. Further, as the size of the body increases the ratio of surface to volume decreases.

Mr. Tiemann.

Fig. 1 shows in section the transference of heat between different portions of the surface and the interior.

ABCD is a section through an object uniformily heated or cooled on all sides. The transference of heat to *ABFE* is through *AB;* to *AED* through *AD*, etc. The progressive effect is indicated by the dotted lines which are rounded at the corners of the section because the penetration is here effected from two surfaces. With the same cross-section, the length up to a certain point, as reflected in the mass, appears to exert an influence, which however requires to be verified by suitable experiments. This does not refer to cases where the piece is so short that greater transference is effected from the ends than from the sides.

Fig. 2 will serve to present more clearly the approximate effect of mass on the physical properties after different treatments.

The curve *AB* is taken to represent the maximum theoretical relation between strength and ductility for steel of one particular composition. Steels of other compositions would have curves differing somewhat from each other. A piece of steel with the properties shown at *A*, with high strength and low ductility, is no better or no worse than a piece with the properties shown at *B*, with low strength and high ductility, or at any other point on this curve (except for certain specific uses), for the relation of the properties in each case is at a maximum. With the properties as at *C*, however, theoretically the strength could be increased to *C'*, leaving the ductility the same; the ductility could be raised to *C''*, leaving the strength the same; or some other maximum relation could be attained as *C'''*.

In practice, with a very small section, the nearest approach to the curve *AB* would probably be as shown by the points *H* or *I*. If the point *C* represents the properties of a large section, these could probably be improved, by annealing to the point *E*, or by quenching and tempering to *F* or *G*. With cooling more rapid than usual, as by quenching in iced brine, followed by tempering, the point *D* might be attained.

The dotted curves *A'B'*, *A''B''*, *A'''B'''*, etc., would then represent the maximum relations which could actually be obtained for sections of different size, the lowest relation being obtained for the largest section.

Mr. Tiemann. The reason for the higher relation of properties in a small section over that in a large section, treated under the same conditions, would appear to be due rather to the condition of the carbon than in accordance with the explanation offered by Mr. Zimmerschied (in Section 3 of his paper) that the "relatively long period of annealing" has "sufficed to toughen the thinner sections in a considerably greater degree than the thicker ones." This is also borne out by the difference in the properties of test specimens cut respectively from near the surface and at the center of large sections, which has resulted in

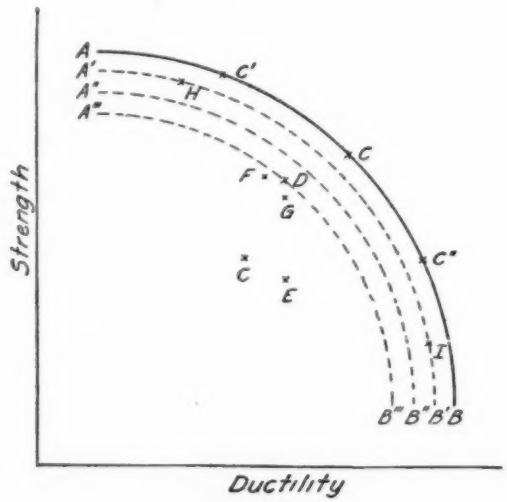


FIG. 2.

the clause in forging specifications that "the axis of the specimen shall be located at any point one-half the distance from the center to the surface and shall be parallel to the axis of the object tested."

I think the objection to the representativeness of this method of testing large sections and that "the figures are not accurate for the real physical properties developed in the pieces" raised by Mr. Nead (last paragraph on the second page of his paper) is more fancied than real. While such a method of testing does not take into account any strains which may affect the

object as a whole,[1] it nevertheless gives a clear indication of the "penetration" of the heat treatment. It would of course be preferable for experimental work to secure results from a number of specimens covering progressively the section from the center to the outside, but owing to the impracticability of testing such large sections *in toto*, it has been considered that the method decided upon gives commercially a thoroughly satisfactory average of the properties. Mr. Tiemann.

Under suitable conditions of heating it is possible to secure a reasonably uniform temperature throughout a fairly large section. If, then, the rate of cooling could be controlled so that a large section could be cooled as rapidly (that is, in the same time) as a smaller object, the uniformity of the material in the two cases should be the same. As a matter of fact, however, such a state of affairs cannot be attained, as the conduction of heat from the center to the outside of a section of any size is relatively slow, and cannot be hastened sufficiently by any means at our command. Even if such were not the case there is another insurmountable obstacle in the path. This is the introduction of excessive strains in large pieces, particularly where there is any irregularity of section. Rupture or incipient cracks resulting from this would not be corrected by any heat treatment alone.

We are therefore confronted with the contradictory state of affairs that the larger the section the more vigorous should be the cooling; and the more vigorous the cooling the greater the liability to excessive strains or rupture. While the component particles of the material may be advantageously affected, the object as a whole suffers. From this it is evident that for any given size or section, there is a maximum relation between the ductility and strength, which decreases as the dimensions increase; that if the strength is maintained constant the ductility must decrease, and *vice versa*, as discussed in connection with Fig. 2.

It must therefore be realized that the possibilities, as

[1] In a paper by Heyn and Bauer is given an interesting discussion of internal strains in cold-worked material and their determination, which is well worth careful study: "Ueber Spannungen in kaltgereckten Metallen," Internat. Ztschr. f. Metallographie, Vol. I, pp. 16–47 (1911).

Mr. Tiemann. regards the physical properties of large sections, are not so great as in the case of small sections, and this should be fully recognized in drawing up the physical requirements of specifications. For, restating the case briefly, under similar circumstances:

1. The condition of the carbon depends upon the initial temperature and the rate of cooling.

2. The rate of cooling depends upon the diameter or thickness of a given section, and probably also to a certain extent upon the length, or in other words upon the mass.

3. The rate of cooling through the critical range, and just below the lower critical point, is of much greater importance than during any subsequent tempering (if quenched).

In planning experiments along these lines, and in reporting results, the following points should be carefully considered, in order that the data may be of permanent value and not open to any question as to their reliability:

1. Brief description of apparatus and pyrometric methods; type of pyrometer and how carefully it is checked; whether pyrometer is in contact with material heated or only in proximity to it; also type of furnace and whether it is uniformly heated as determined by actual test;

2. There should be a sufficient number of tests to yield reliable averages;

3. As wide a range as possible in the physical properties should be covered, preferably starting with the most ductile condition (quenched and fully annealed rather than simply annealed) as a standard for comparison;

4. Length of time of heating to desired temperature;

5. Length of time held at desired temperature;

6. Volume of quenching medium;

7. Temperature of quenching medium;

8. Length of time required for quenching;

9. Length of time of heating for tempering;

10. Whether held any time at maximum temperature;

11. Check analyses should be made of different bars or pieces, particularly of test specimens, where discordant results are obtained. If this is not sufficient, further careful endeavor should be made to discover the cause of the discrepancy to prove

that some general condition is not at fault throughout the experiments. Mr. Tiemann

The following remarks may prove of interest particularly in connection with certain conditions mentioned in Mr. Hall's paper:

One of the effects of mass on heat treatment has not received very much attention, at least in the technical press, probably because it is principally mechanical. This has to do with the structure of castings, more especially those of large section which have cooled very slowly because of their large mass, usually materially assisted by the refractory (non-conducting) nature of the molds in which they have been cast.

Particularly where the initial (pouring) temperature of the steel has been high, crystals are frequently found which are $\frac{3}{8}$ to $\frac{1}{2}$ in., or even larger, across, and a casting in such a condition is unable to withstand any violent shocks or stresses such as those to which a roll, for example, is subjected. Howe has termed this coarsely crystalline condition "ingotism." To correct this, the material is usually annealed by extremely slow heating to a temperature somewhat above the critical point, held at this temperature for some time, and then slowly cooled.

If quenching in water or oil can be resorted to without the danger of setting up cracks or excessive strains, a finer grain will be secured than by simple annealing, which latter treatment or a partial reheating (tempering) will then be applied to remove as far as possible all brittleness, and thereby render the material tougher because more ductile.

With either of these treatments—even when repeated—there will almost invariably remain in castings of any considerable size some large isolated crystals which stand out prominently in the surface of a fracture, surrounded by fine-grained material corresponding to the given treatment, having apparently withstood any purely thermal treatment. The only method which will break up such crystals is forging or rolling (mechanical working) at the relatively high temperature customary for these operations.

Such a condition is commonly claimed by the workmen to be due to too high a pouring temperature, producing a structure which resists the "penetration" of heat treatment. That such

Mr. Tiemann. a statement is true of the effect, but not of the cause, can be readily demonstrated.

A miscroscopic examination of the interior of such crystals will show that the structure is as fine as that of the surrounding fine-grained material, hence (under proper conditions) the effect of the heat treatment has penetrated to all parts alike. Upon a little more than a casual observation it will be found that the isolated crystals are actually separated in places from the surrounding mass, and in some cases the space is sufficient to permit the insertion of a penknife blade or other slender object to a depth of $\frac{1}{4}$ in. or even more. In other words, we are here dealing, not with one united whole, but with several separate and distinct pieces of steel; and it would be as reasonable to expect two pieces of steel, one simply laid on top of the other and in imperfect contact, to become joined together by heating alone, as for these crystals to be incorporated with the surrounding mass by the same operation. As the surfaces are free from oxidation, forging or rolling causes welding to take place, as has been demonstrated by Stead in the case of blowholes.

The separation of the crystals is evidently due to the contraction after solidification, the original outside dimensions having been determined by the walls of the mold, and the cooling proceeding inward. Where the strains have been insufficient to cause actual separation, simple heat treatment will have a refining effect, except, perhaps, where the strains are very great. This condition is probably largely responsible for the brittle and crumbly condition of overheated (not burnt) steel, although other factors also enter into the problem.

Mr. MacPherran. MR. R. S. MACPHERRAN (*by letter*).—The experience of the Allis-Chalmers Manufacturing Co. agrees in general with Mr. Nead's conclusions. We have never worked out a curve or tested graded sections, but have found that the physical properties tend to fall off as the section increases. Results of tests on automobile material are difficult to equal in large forgings. This is only to be expected from the greater difficulty of quickly cooling a large section. Our sections begin at about where Mr. Nead's leave off, and I am giving in Tables I and II a few typical results from our records in the hope that they may be of interest to the Society.

Mr. MacPherran.

We heat-treat two classes of large chrome-vanadium steel forgings:

1. Rotor-coil support rings with a metal thickness of 2 to 3 in.

2. Non-fatigue shafts with a metal thickness of 10 in. and over.

It is unfortunate for this discussion that we cannot directly compare the results on one class of forgings with the results on

TABLE I.—ANALYSES OF STEEL.

Heat No.	Percentage of						
	Carbon.	Phosphorus	Sulphur.	Manganese.	Silicon.	Chromium.	Vanadium.
1....	0.29	0.011	0.022	0.54	0.10	1.05	0.20
2....	0.32	0.007	0.019	0.48	0.11	0.90	0.22
3....	0.31	0.011	0.020	0.46	0.13	0.90	0.20

TABLE II.—PHYSICAL TESTS.

ROTOR-COIL SUPPORT RINGS.

Heat No.	Thickness of Section, in.	Weight of Forging, lb.	Yield Point, lb. per sq. in.	Tensile Strength, lb. per sq. in.	Elongation in 2 in., per cent.	Reduction of Area, per cent.
1.....	2	1 000	119 300	136 750	18.5	49.1
1.....	2	1 000	112 200	126 850	17.5	43.3
1.....	2	1 000	115 250	133 200	17.5	49.1
Average...	.....	.....	115 910	132 260	17.8	47.1
1.....	3	3 000	107 750	128 550	18.0	54.6
1.....	3	3 000	106 400	128 500	17.0	49.1
Average...	.....	.....	107 070	128 520	17.5	51.8
2.....	2	1 500	109 050	129 250	19.5	54.6
2.....	2	1 500	110 450	130 700	20.0	57.2
2.....	2	1 000	109 300	123 550	20.5	59.8
Average...	.....	.....	109 600	127 830	20.0	57.2
2.....	3	3 000	108 200	130 350	18.5	49.1
2.....	3	3 000	109 200	132 400	18.0	49.1
2.....	3	3 000	105 000	126 700	20.0	54.6
Average...	.....	.....	107 500	129 810	18.8	51.6
SHAFTS.						
3.....	10	9000	112 100	126 100	19.0	54.6
3.....	10	9000	115 350	130 000	20.0	64.7
Average...	.....	.....	113 730	128 050	19.5	59.7

Mr. MacPherran. the other. This is due to the fact that the test bars were taken tangentially from the rotor-coil support rings and longitudinally from the shafts. The difference between the tests of rotor-coil support rings with the 2-in. section and those with the 3-in. section is slight, although the former average higher in the yield point and elongation. These tests were made months apart, and are not the result of any investigation. They are merely routine tests on our own forgings, made in order to pass a certain specification. I regret that complete data are not available on a number of our heat-treated shafts much thicker and heavier than those here given.

The forgings were all quenched at 1600° F., and annealed under like conditions. The temperature of the oil before quenching was about 60° F. The hot oil rising to the surface after quenching is continuously drawn from the tank and cooled in water-cooled circulating pipes outside the building. Fresh cold oil is constantly being forced up around the forging during time of cooling.

The forgings were all made from the three heats, analyses of which are given in Table I.

Our rotor-coil support rings are hoop-shaped forgings, varying from 2 ft. in diameter for small sizes to 4 ft. in diameter for larger sizes. The rims vary from 11 to 17 in. deep and have a metal thickness as given. The test bars were taken tangentially from the rim of the forging with the axis of bar parallel to the greatest diameter of the forging.

The shafts were solid shafts 15 ft. long, 15 in. in diameter in the center and tapering to 10 in. in diameter at the end. The test bars were hollow-drilled half-way from the center to the outside of the prolongation, which was 10 in. in diameter. The axis of the bar was parallel to the length of the shaft. Standard navy test bars with threaded ends were used, and elongation was measured in 2 in. All fractures were gray. The yield point was taken at the drop of beam. All forgings were made from chrome-vanadium steel ingots 26 in. in diameter.

I wish to thank Mr. Freeman, Superintendent of our Forge Shop, for his cooperation in preparing the results as given.

Mr. Mathews. MR. J. A. MATHEWS (*by letter*).—The results presented by Mr. Nead are of considerable importance, not so much on account

of the actual data presented, as because of the importance of the subject generally to designing engineers . There is very little in the technical literature calling attention to the effect of mass on the physical properties developed by heat treatment. Mr. Mathews.

The writer of this discussion called attention to the importance of this in an address before the Franklin Institute upon "Alloy Steels for Motor Car Construction."[1] In this article, attention was called to the importance of not being misled by remarkably high tensile values afforded when a standard test piece is heat-treated and then pulled, and to the danger of using such figures as a guide to the physical properties likely to result when a much larger mass is treated.

Mr. Nead's paper gives some specific, quantitative information as to just how much difference may be expected in heat-treated pieces of various sizes but made from the same heat of steel. The results given for the chrome-vanadium steel are very satisfactory but, as regards the nickel steel used in his experiments, it would have been better had a higher-carbon steel been chosen; first, for the reason that it would have responded better to the heat treatments, and second, because nickel steel of about 0.20 per cent carbon would ordinarily be used for case-hardened parts rather than for heat-treated parts. It would, also, have added to the value of the results had it been possible to have done all the tension testing in a single laboratory and with the same operators.

Some years ago, we made a similar investigation in our laboratories, but confined our attention to the Brinell hardness numbers; first, on pieces of variable size taken from a single heat and all subjected to the same heat treatment, and second, on cross-sections cut from $3\frac{1}{4}$-in. square billets and tested all over from outside to inside. As there is a fairly definite relation between the Brinell hardness and the physical qualities, our experiments were of some value in confirming the work of Mr. Nead.

In the first of these experiments, we forged square bars varying in size from $\frac{3}{8}$ in. square up to $3\frac{1}{4}$ in. square, there being twelve different bars in the series. All of these were made from

[1] Journal of the Franklin Institute, Vol. 167, p. 395.

Mr. Mathews. the same heat of steel. After oil-tempering, the Brinell hardness was taken at the center of the flat sides of the square bars. In the case of a 0.50-per-cent-carbon chrome-vanadium steel similar to that used in Mr. Nead's experiment, we found after tempering in oil a gradual decline in hardness from 595 on the $\frac{3}{8}$-in. square bar to 350 on the $3\frac{1}{4}$-in. square bar. After drawing the temper to 600° F., the hardness had dropped from 435 to 325 respectively for the two sizes, and intermediate sizes gave intermediate results. Upon further drawing to 1200° F., the hardness varied from 353 to 278. It is interesting to note that the greater the initial hardness, the more it seems to have been affected by drawing the temper; that is, the percentage drop in hardness on the small bars is much greater than on the large bars.

From the $3\frac{1}{4}$-in. square bar, representing the largest piece of the series, we cut a transverse section and, after ruling it off into squares, tested the hardness systematically from outside to inside. This test showed a gradual decrease in hardness from the corners toward the center of the flat sides and also toward the geometric center of the transverse section of bar.

Similar results were obtained with nickel steel and chrome-nickel steel, and it is hoped to present these results more in detail at some future time.

Mr. Zimmerschied. MR. ZIMMERSCHEID (*Author's closure by letter*).—Since the author's paper was presented, measurements of the pulling speeds have been made; they were found to vary between 0.338 in. per minute per inch of gage length on the specimen 0.505 in. in diameter, to 0.18 in. per minute per inch of gage length on the specimen 1.125 in. in diameter. Both of these speeds are so low that we do not believe they can influence the results to any appreciable extent.

We have also examined the report of Mr. Devries on spring steel experiments,[1] and believe that he was in reality dealing with much greater differences in temperature than he realized. His samples were dropped end-on into water, and found to be much softer on the end last immersed than on the end first immersed. Here he confronts the condition of quenching in a

[1] "Mechanical Tests of Heat-Treated Spring Steel," R. P. Devries, p. 550.—ED.

liquid which is near its boiling point, for the frictional effect of the falling steel on the water tends to drag the already heated liquid along the surface until the end last immersed may be subjected actually to steam alone for a short time. We have found in those cases where it is necessary to quench long pieces end-on for other considerations, that special apparatus is necessary to insure hardness over the whole length. Again, if we attempt to drop a layer of metal into a bath of water and then to dump another layer on top of that, or even close above it, the top layer will not be hard, because of the hot water rising from below; yet the average temperature of the whole bath may have risen but a couple of degrees. In answer to his question on the possibility of duplicating results when the temperature of the bath varies, we should say that our water tanks vary between 45° F. early on winter mornings and 110° F. on hot summer days, yet this makes less than five points difference in scleroscope hardness on a given piece of case-hardened work. Mr. Zimmerschied.

Referring to Mr. Kenney's remarks: the rate of cooling in all cases was too great to admit of the separation of any structurally free ferrite, as confirmed by microscopic examination. When the author wrote that the difference in properties between thin and thick sections was due to the longer annealing of the former, he was speaking of the proximate cause, in general terms. It goes without saying that the ultimate cause of all the differences cited is primarily the variation in the carbon compounds and in the structure as a whole.

The above covers Mr. Tiemann's remarks on the same point. His statement that "a much higher relation between ductility and strength can be obtained by quenching and tempering than by simple annealing," because "at the relatively low temperatures used for tempering, the pearlite has but little opportunity to become coarsened," must be a mistake. Pearlite never enters into the question with a piece of any ordinary size quenched from above the critical point. The "higher relation" cited is due to the absence of lamellar pearlite, and the substitution of troostite or cementite, or even of spherulized carbides. The formation of pearlite and an excess constituent as a consequence of tempering, described in his seventh paragraph, is foreign to all published experience, or else to accepted terminology with respect to the word "pearlite."

Mr. Zimmerschied. We also hold (as stated in his sixth paragraph) that the carbon above A3 is present in solid solution as a carbide, or carbides. From all the data we have been able to collect, the lines *AB* (his Fig. 2), plotted as tensile strengths against reductions of area, should be almost straight, bending toward the *X* axis near the bottom.

Concerning the fundamental conceptions involved in heat treatment, the author has spent a number of years on the evolution of a simple, satisfactory, and comprehensive presentation of quenching phenomena. We hope to make its exposition the subject of a future article. The author's present paper was made as short and concise as possible, but we fear the experiment in brevity must be counted a failure. Its purpose is voiced in the last paragraph; all of it was written for those who understand at least the simple essentials of heat-treatment phenomena, and on that account, only the bare, new or confirmatory resultants were published, together with such data as we considered essential to their understanding and appraisal.

Our kindest thanks are due to those who have accepted and discussed it so fully in that light, and our gratitude to the gentlemen who have taken the pains to submit remarks on the fundamentals involved. All have convinced us that the little note was timely, and the inspiration aroused by so full a discussion, together with the valuable points raised in criticism, will guide us to a much more comprehensive report in the near future. Thus is our first aim fulfilled.

Mr. Hall. MR. J. H. HALL (*Author's closure by letter*).—In reply to Mr. Kenney, I may say that in presenting this paper I had expected to meet the criticism that the heat treatment of steel castings by rapid cooling is not practicable, for in the days when this process was first used in the steel foundry where it was worked out, I had to listen to dire predictions as to what would happen to castings that had been quenched, when they were put up against hard service.

The situation at that time was simply this—the foundry in question was in a position where it was essential for them to turn out heavy machinery castings of certain types, which were to be subjected to extremely severe service, involving both heavy wear and sudden severe shocks. Steels of a great many

different sorts, ranging from quite soft to very hard steel, heat-treated in the usual manner by annealing and slow cooling, had been tried, and uniformly found wanting, and a steel had to be produced that would give good resistance to wear and at the same time not break. **Mr. Hall.**

By such heat treatment as described in my paper, castings ranging in weight from 200 to 2000 lb., were produced to the number of three or four thousand, which successfully stood up to the service demanded of them, where other cast steels had failed. In an experience of four years not one casting failed in service from the effect of shrinkage strains or quenching cracks, and the number of castings that cracked in treatment was but a very small fraction of one per cent. These castings were of a great variety of sections and were found to be uniformly successful. If such experience is not practical, nothing is.

Mr. Kenney's point indeed is not well taken, in this respect, that though after the first (rapid) cooling, a casting of unequal section is in a state of heavy strain, yet after the second heating, these strains are completely removed. This has been demonstrated by most careful tests of full-size castings, as well as of the strain test bars described in the paper. The question is one for the manufacturer, rather than the consumer, since the only trouble that can arise from the quenching strains is the liability of the castings to crack if incautiously heated after quenching. Great care has of course to be taken in the second heating, to see that the castings are brought gradually to the temperature desired. If due care is not used at this stage, the manufacturer will suffer in lost castings, but a casting properly quenched and annealed is as free from strains as it can be made by any annealing process and will cause no trouble in service from that source.

MECHANICAL TESTS OF HEAT-TREATED SPRING STEEL.

By R. P. Devries.

This paper attempts to give briefly some of the results of an investigation of the mechanical properties of certain steels which are seldom if ever used except in a heat-treated condition. That part of the work which deals with a 1-per-cent-carbon tool or spring steel was undertaken by the Bureau of Standards, in cooperation with the Pennsylvania Railroad Co. They furnished the steel in specimen form, sending part of it in a heat-treated condition and part in an annealed condition to be heat-treated at the Bureau. The work, which has been under way for some time, has been done with the cooperation of the chemical, heat, magnetic and mechanical testing divisions of the Bureau.

The chemical composition of the carbon steel, expressed in per cent, is as follows:

Carbon.	Sulphur.	Phosphorus.	Manganese.	Silicon.
1.01	0.045	0.035	0.41	0.054
1.00	0.045	0.035	0.42	0.054
1.01	0.045	0.035	0.41	0.051

Some of the carbon steels included in this investigation varied somewhat in chemical composition from the above analysis but none of these variations were greater than allowed by the specifications under which this steel is bought. The results obtained on these steels, therefore, represent current practice as far as the chemical composition and thermal treatment are concerned.

Mechanical Tests.

The mechanical tests included the transverse test, cold-bend test, Brinell hardness test, and scleroscope test.

Transverse Tests.—The transverse tests were made in a 2000-lb. screw machine on specimens 10 in. in length and approximately 0.36 by 1.2 in. cross-section, using a 9-in. span. The deflections were measured with a calibrated screw of 0.5-mm.

pitch. The head of the screw carried a dial which made it possible to read deflections of 1 micron (0.0000397 in.). In Fig. 1 a few typical stress-strain diagrams are plotted. The load at which the deflection ceases to be proportional can be easily determined by inspection of the plotted curves. The fiber

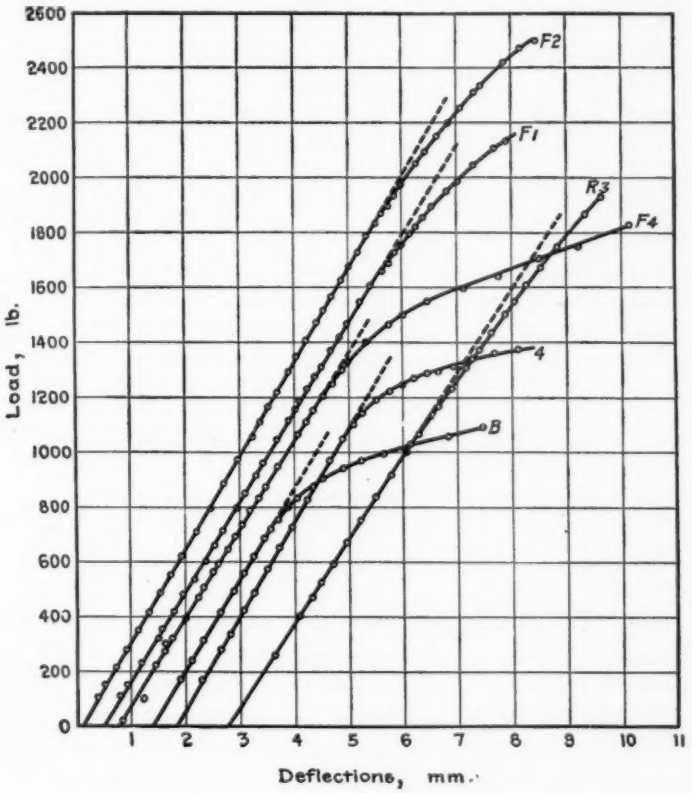


FIG. 1.—Typical Transverse Tests.

stress in pounds per square inch on the extreme fiber, at which the load and deflection cease to be proportional calculated from the well-known beam formula, will be referred to throughout as the proportional limit.

Cold-Bend Tests.—The bars after being stressed in the transverse test were subjected to bending around a pin 1½ in. in

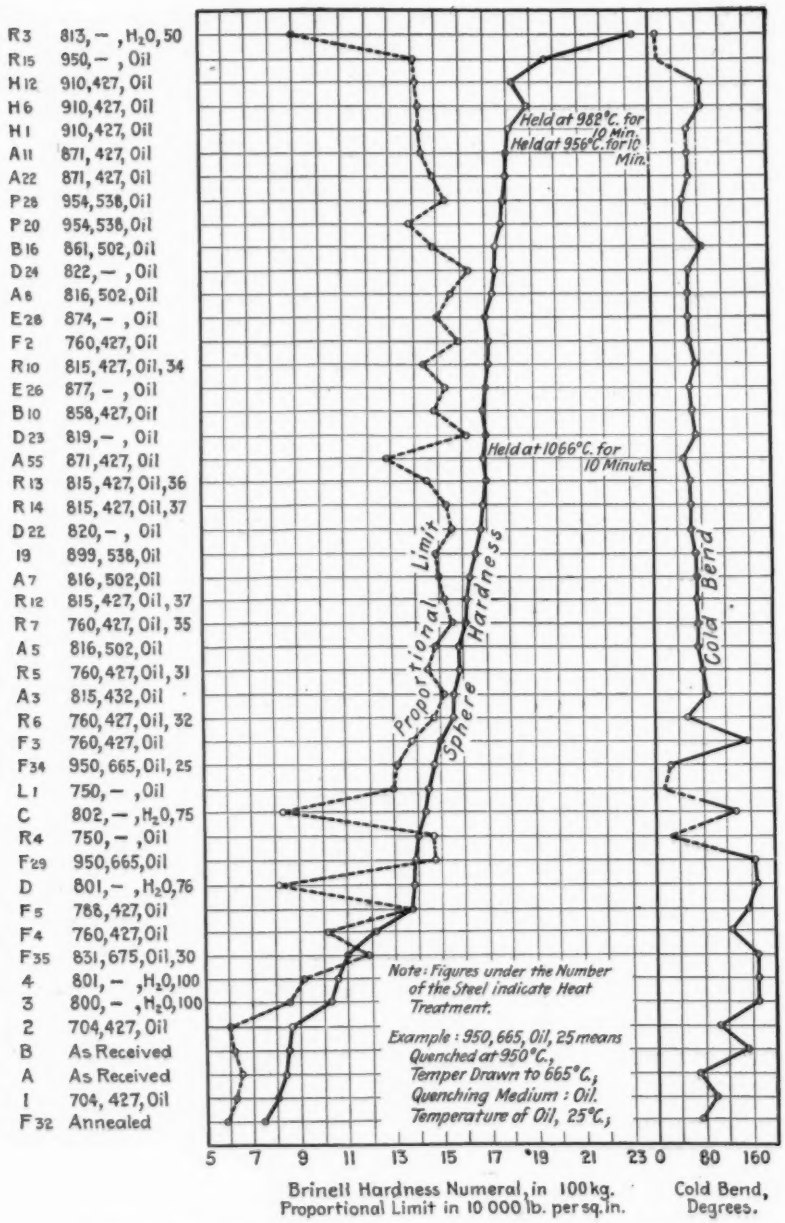


FIG. 2.—Results of Mechanical Tests on High-Carbon Steel.

diameter. The distance from the center of the pin to the edge of bending contact was 5 in. The bar was placed in the machine so that the side previously in tension was again subjected to tension and then bent to rupture or the greatest bend obtainable; the bend being measured in degrees of circular arc.

Hardness.—The Brinell hardness tests[1] were made on the transverse test specimens by measuring the permanent depth of indentation for successively applied loads and determining from the linear relation of load to depth, the amount of load required to produce a permanent indentation 0.1 mm. in depth. The diameter of the ball used was 10 mm. The scleroscope test was also used for determining the hardness. The hardness tests were made perpendicular to the plane of rolling of the steel bars.

In Fig. 2 the stress at the proportional limit, the bend in degrees and the Brinell hardness are graphically compared.

The hardness values of the different bars plotted in Fig. 2 are in all cases a mean of two or three values. The hardness of the bars which lie between hardness numerals 1500 and 1800 kg. are fairly uniform. Below 1500 hardness numeral many of the bars vary from 10 to 30 per cent from one end to the other. Many of the apparent inconsistencies of the transverse and cold-bending tests can be accounted for by the inhomogeneity shown to exist by the hardness test. Bars R4 and L1 ruptured in transverse test at a permanent set of only a few millimeters, while bars 30 per cent harder bent to an angle of 60 to 70 deg. The inhomogeneity of these bars as shown by the hardness tests is probably sufficient to account for the low ductility. The hardness of the two bars mentioned varied 30 per cent from one end to another. In the transverse test the externally applied load demands that the hard and the less hard part of the bar shall extend on the tension or compress on the compression side at the same rate. Since the steel cannot meet these conflicting demands it may break with less display of ductility than if the hardness was greater but uniform.

An inspection of the curves in Fig. 2 shows that steels which have nominally received the same heat treatment are widely

[1] For particulars concerning these tests see *Proceedings*, Am. Soc. Test. Mats., Vol. XI, pp. 709–732 (1911).

different in their mechanical characteristics. This is shown more in detail by the results in Table I. The four steels in this table cover a large part of the range of results obtained by different thermal treatments. It is difficult to believe that one

TABLE I.—RESULTS OBTAINED ON BARS SUBJECTED TO SAME NOMINAL HEAT TREATMENT.

No. of Steel Bar.	Heat Treatment, temperature in deg. Cent.			Sphere Hardness Numeral, kg.			Proportional Limit, lb. per sq. in.	Cold Bend, degrees.
	Quenched at	Drawn to	Temperature of Oil.	End No. 1.	End No. 2.	Mean.		
1.....	760	583	24	1 821	1 335	1 578	141 000	121.5
2.....	760	583	24	1 705	1 765	1 735	159 800	64.0
3.....	760	583	24	1 488	1 515	1 501	137 500	157.0
4.....	760	583	24	1 268	1 162	1 215	100 900	123.0

end of a steel bar, 10 in. long, exposed to the air a fraction of a second longer than the other end, could drop below the critical temperature. Possibly the difference in hardness of the two ends was due to the increase in temperature of the quenching

TABLE II.—EFFECT OF QUENCHING AT DIFFERENT TEMPERATURES.

No. of Steel Bar.	Heat Treatment, temperature in deg. Cent.			Sphere Hardness Numeral, kg.			Proportional Limit, lb. per sq. in.
	Quenched at	Drawn to	Temperature of Oil.	End Immersed First.	End Immersed Last.	Mean Value.	
S_1.....	Tested as received			....	....	1 136	113 500
S_2.....	735	...	63	1 552	1 012	1 282	118 700
S_3.....	820	...	60	1 751	1 197	1 474	128 500
S_4.....	875	...	52	1 785	1 623	1 704	151 800
S_5.....	935	...	41	2 392	2 300	2 346	154 700
S_6.....	985	...	24	2 457	2 352	2 404	.....
S_7.....	800	...	25.2	1 505	1 480	1 492	.....

medium causing the end entering last to receive a slower cooling through the critical temperature.

The hardness and proportional limit of seven other steels are given in Table II. It will be seen that the steels quenched

at the lower temperatures are hardest at the end entering the bath first. Precautions for obtaining a uniform quench were observed, such as stirring the specimen in the bath after immersion. The temperature of the bath rose after the quenching of each bar. The specimens quenched at the lower temperatures are comparatively soft, inhomogeneous and have a low proportional limit. Another bar, No. 7, was subsequently quenched at a lower temperature than bar No. 3, but the temperature of the oil was held at 25°.2 C. The hardness results obtained show that careful control of the temperature of the quenching

TABLE III.—VARIATIONS IN MECHANICAL PROPERTIES OF BARS RECEIVING SAME HEAT TREATMENT, PROBABLY DUE TO VARIATIONS IN TEMPERATURE OF OIL.

No. of Steel Bar.	Heat Treatment, temperature in deg. Cent.			Sphere Hardness Numeral, kg.			Proportional Limit, lb. per sq. in.	Cold Bend, degrees.
	Quenched at	Drawn to	Temperature of Oil.	End No.1.	End No.2.	Mean.		
H1R...	760	427	24	1 754	1 665	1 709	138 700	64.0
H5R...	760	427	31	1 592	1 587	1 589	144 100	79.0
H6R...	760	427	32	1 530	1 555	1 542	146 200	51.0
H7R...	760	427	35	1 620	1 605	1 612	155 000	55.5
H10R..	815	427	34	1 660	1 755	1 707	142 600	73.5
H12R..	815	427	37	1 620	1 615	1 617	152 700	69.5
H13R..	815	427	35.5	1 700	1 678	1 689	143 900	62.0
H14R..	815	427	37	1 680	1 634	1 657	152 200	63.0

medium is as important as the control of the temperature of the furnace.

The detailed test results of two sets of bars quenched at two different temperatures are given in Table III. The results on these bars seem to indicate that comparatively small changes in temperature of the quenching medium play an important part in the heat treatment of steel.

EFFECTS OF QUENCHING IN WATER OF DIFFERENT TEMPERATURES.

When bars were quenched in oil by immersing one end before the other, the results show that the hardness may differ

considerably from end to end. When steels were quenched in water, to make the quenching or hardening as uniform as possible, the bars were immersed by allowing them to drop in the bath with their length parallel to the surface of the water. Table IV gives the results of hardness, proportional limit and cold bend for the steels quenched in water. The fact that the

TABLE IV.—RESULTS ON STEELS QUENCHED IN WATER OF DIFFERENT TEMPERATURE.

No. of Steel Bar.	Heat Treatment, temperature in deg. Cent.			Brinell Hardness Numeral, kg. (Tested on Flat.)				Proportional Limit, lb. per sq. in.	Cold Bend, degrees.
	Quenched at	Drawn to	Temperature of Water.	Near Edge No. 1.	Near Middle.	Near Edge No. 2.	Mean.		
3.....	800	...	100	1 020	1 037	1 046	1 031	91 900	168[1]
4.....	801	...	100	1 056	1 068	1 042	1 055	85 400	168[1]
D.....	801	...	76	1 660	1 175	1 296	1 377	81 750	168[1]
H11R..	798	...	52	2 440	1 390	5 065	2 965	.....	6
H11R..	798	655	52	891	950	968	936	.....	...
C.....	802	...	75	1 725	1 212	1 363	1 433	83 200	136
C.....	802	655	52	....	....	....	....	.....	...
H3R...	813	...	50	1 570	1 178	4 230	2 326	89 550	5
H3R...	813	655	50	958	935	948	947	.....	...
R6.....	815	...	40	2 000	1 420	2 000	1 810	.....	...
R6.....	815	700	40	893	873	882	882	.....	...
K1....	800	...	30	....	....	....	....	.....	...
K1....	...	330	...	....	....	....	....	.....	...
K2....	795	...	30	4 630	1 598	1 553	2 660	.....	...
K2....	...	455	...	1 810	1 765	1 820	1 798	.....	...
K3....	800	...	30	....	1 530	5 750	3 640	.....	...
K3....	...	365	...	....	1 332	1 233	1 332	.....	...

[1] Did not break.

edges of the bars quenched in water at 75° C. or under show a considerable increase in hardness over the center, must of course be attributed to the geometry of the specimen; the square sides giving a quicker cooling through the critical temperature. Some of the water-quenched specimens show a difference in hardness between the two edges of the bar which points to the same

conclusion reached regarding the oil-quenched specimens, namely, that the quenching raises the temperature of the bath, producing a slower cooling through the critical range and a consequent loss in hardness. Since water at 100° C. under atmospheric pressure cannot rise in temperature it would make an ideal quenching medium from the standpoint of uniformity.

Bars H11R and H3R bent only 6 and 5 deg. respectively, and the fracture showed plainly a different structure from edge to middle. If these bars had had a uniform hardness no greater than that existing at the middle of its width, the angle of bend would, no doubt, have compared favorably with bars Nos. 3 and 4. The low hardness at the middle of the width of bars quenched at 800° C. in water at 50° C. is difficult to account for. Bars quenched at 800° C. in oil at 25° C. show a uniform hardness greater than the minimum found on the water-quenched

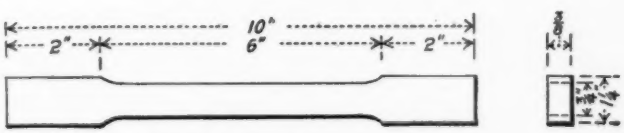


FIG. 3.—Tension Test Specimen.

specimens. The differences in hardness that exist in the water-quenched specimens are wholly or in part removed, depending on the drawing temperature to which the bars are subjected.

TENSION TESTS OF HIGH-CARBON STEELS.

Steels which have been heat-treated to bring out their best qualities are very seldom used in pure tension. That is one reason why the transverse test was chosen to determine the proportional limit and the cold-bend test as a measure of the relative ductility. However, the transverse test if carried to rupture gives no idea of the ultimate strength of steel, for it is a well-known fact that the modulus of rupture obtained from this test is of no real value in the judging of steel. The tension tests are a more standard means of judging strength and ductility in steel and a knowledge of these properties makes comparisons with other steels easier. Therefore, a few specimens cover-

ing a large range of hardness were tested in tension. The form of these specimens is shown in Fig. 3. The results of the tests are given in Table V.

TABLE V.—RESULTS OF TENSION TESTS ON CARBON STEELS.

No. of Steel Bar.	Heat Treatment, temperature in deg. Cent.				Proportional Limit, lb. per sq. in.	Ultimate Strength, lb. per sq. in.	Elongation in 5 in., per cent.	Reduction of Area, per cent.
	Quenched at	Drawn to	Quenching Bath.	Temperature of Bath.				
R2....	815	455	Oil	20	113 500	199 500	7.0	7.8
R3....	825	455	"	20	113 500	214 300	6.0	13.2
R4....	815	585	"	20	102 500	156 700	7.2	8.5
R5....	815	655	"	20	70 000	127 800	11.5	22.0
R6....	815	700	Water	40	80 100	106 000	14.4	33.6
S2.....	815	700	Water	50	76 500	106 500	15.0	33.0

An idea of the ductility and strength of bars tested in transverse and cold-bend tests may be obtained by comparing the

TABLE VI.—THE RELATION BETWEEN THE BRINELL TEST AND THE ULTIMATE STRENGTH.

No. of Steel Bar.	Heat Treatment, temperature in deg. Cent.				Brinell Hardness Numeral, kg.			Ultimate Strength, lb. per sq. in.	
	Quenched at	Drawn to	Quenching Bath.	Temperature of Bath.	End No. 1.	End No. 2.	Mean.	Calculated from Sphere Hardness Numeral.	Results of Tension Test.
R3....	825	455	Oil	20	1 930	1 891	1 910	216 500	214 300
R2....	815	455	"	20	1 941	1 569	1 755	200 500	199 500
R4....	815	585	"	20	1 250	1 201	1 225	146 000	156 700
R5....	815	655	"	20	1 012	998	1 005	123 400	127 800
S2.....	815	700	Water	50	878	884	881	110 600	106 500
R6....	815	700	Water	40	873	893	883	110 800	106 000

tension-test results with results obtained on bars of similar hardness, shown in Fig. 2.

The Brinell hardness results obtained on the tension test bars are given in Table VI.

The values of ultimate strength in pounds per square inch calculated by using the relation between Brinell hardness and ultimate strength, obtained on various chrome-vanadium and other alloy steels,[1] are also given in Table VI.

In Table VII are given the ultimate strength of chrome-vanadium steels in different states of heat treatment both as calculated from the Brinell test and as obtained in tension test on a standard 2-in. gage length, threaded-grip tension specimen. The ultimate strength can be obtained from the Brinell hardness

TABLE VII.—ULTIMATE STRENGTH CALCULATED FROM SPHERE HARDNESS NUMERAL FOR CHROME-VANADIUM STEELS.

No. of Steel Bar.	Sphere Hardness Numeral, kg.	Ultimate Strength, lb. per sq. in.	
		Calculated from Hardness Numeral.	Results of Tension Test.
1	1 346	158 500	155 000
2	1 459	170 200	171 000
3	789	101 500	102 100
4	815	104 000	103 600
5	968	116 800	116 000
6	1 333	157 200	154 000
7	1 315	155 500	150 000
8	1 509	175 500	179 200
9	1 278	151 800	146 000

test with equal accuracy for the alloy steels and high-carbon steels.[2] This is contrary to the findings of different Continental investigators who advised that slightly different coefficients be used for steels of different carbon content in calculating ultimate strength from Brinell hardness. The special method used in determining the hardness may account for the fact that one coefficient can be used.

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[1] *Proceedings*, International Association for Testing Materials, New York Congress, 1912.

[2] "The Brinell Hardness Test and Its Practical Applications," Fourth Congress of the International Association for Testing Materials, Brussels, 1906.

CONCLUSION.

This paper has dealt in some detail with the inhomogeneity found in hardened steel, because the idea is more or less prevalent that the hardness test is useful only in a restricted sense. It has been said that it tests only a small portion of a given bar and therefore can not be representative even of a large test specimen. If several Brinell tests are made on inhomogeneous heat-treated steel, an average quality factor can be obtained for the steel by this hardness test as well as by a tension or transverse test that can from its very nature yield nothing but an average value. If a bar of homogeneous heat-treated steel is to be tested, a few hardness tests can be made and the fact ascertained, whereas a whole specimen when tested in tension or transversely gives but small indication of homogeneity.

Some work has been done towards relating the results of hardness and transverse tests in the excellent report of the Spring Steel Committee of this Society.[1] In this paper no attempt has been made to show a definite relation between the results of these tests because it soon became apparent that the same nominal heat treatments did not produce like results. Much of the work has been done to discover the reasons responsible for this failure; for it is evident that no test can identify a steel as having had a certain heat treatment unless a standard result for that particular heat treatment has been ascertained.

Another reason for not attempting to definitely relate the results of different tests is that the work is as yet incomplete, and was presented at this time in the hope that its further progress might be benefited through discussion and suggestions.

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[1] "Report of Committee A-7," *Proceedings*, Am. Soc. Test. Mats., Vol XI, p. 115 (1911).

DISCUSSION.

Mr. Lanza.

MR. GAETANO LANZA.—I should like to ask the speaker whether he used any spans longer than 9 in., and if so how the results compared with those obtained with the 9-in. spans.

Mr. Devries.

MR. R. P. DEVRIES.—No, because we continued to use the same span, or approximately the same that the Pennsylvania Railroad Co. had been using in their testing laboratory, and which was reported upon, I think, a few years ago in the report of the Committee on Spring Steel.[1]

Mr. Lanza.

MR. LANZA.—The result of my own experience has been that the value of the elastic limit obtained in experiments of this character gradually decreases as the span increases, until a span is reached at least as great as 18 in., and that with spans of from 18 to about 40 in. the values obtained for elastic limit do not vary greatly. Moreover, these longer spans conform better with the spans employed in practice.

Mr. Devries.

MR. DEVRIES.—I might say in reply, that a high elastic limit is what we were looking for. We have found that it is possible to obtain greater hardness in a steel, which also indicates a greater ultimate strength, by raising the quenching temperature. We found at the same time, however, that this treatment does not increase the elastic limit; in fact, the elastic limit is often lowered by this operation.

I am glad to learn of the influence of span on the results of transverse tests and hope to profit by it in the future; in the past we were most concerned to find by relative tests how to heat-treat a 1-per-cent-carbon steel so as to make it best for spring purposes.

[1] "Report of Committee A-7," *Proceedings*, Am. Soc. Test. Mats., Vol. XI, p. 115 (1911).

RESISTANCE OF STEELS TO WEAR IN RELATION TO THEIR HARDNESS AND TENSILE PROPERTIES.

By George L. Norris.

The increasing speeds and heavy duty of machinery and motive power with resultant shortening of length of service of parts through rapid wear, makes the study of wear-resisting qualities of metals, especially steel, one of increasing importance. In the railway field the increasing wear of tires and rails due to increased loads and speeds is a serious matter. Not only is it desirable to have high resistance to wear, but it is necessary to have other qualities, strength and toughness, to insure against failure or breakage. The tests described in this paper were undertaken with the object of studying the relations, if any, between the wear-resistance of various steels and the various physical properties of elastic limit, tensile strength, and hardness. Owing to several protracted interruptions, only a relatively small proportion of the tests projected have so far been completed.

There are three classes of wear:

1. Abrasion, such as that to which grinding, crushing and excavating machinery is subjected;

2. Lubricated sliding or rolling friction, such as that upon machine parts, axles, shafting, etc.;

3. Dry rolling friction, such as that between wheels and rails.

Abrasion.—The first class is in many ways less important than the other two. It has, however, been utilized frequently as a means of comparing the wearing qualities of metals for all three classes. The machines for the purpose are some form of grinding machine, and the specimens are ground or abraded under a constant pressure for a certain length of time. The amount of metal removed under these conditions determines the relative wearing value. The most extensive investigations along this line were made by F. Robin, and published in the Proceedings of the British Iron and Steel Institute, 1910.

Lubricated Friction.—Investigations of wear by lubricated friction have been in the past largely confined to bearing metals rather than to steel. This has been due undoubtedly to the fact that steel is usually worked against soft bearing metals or bronzes, which wear much faster.

The investigation of the wear-resistance of steel and iron under lubricated friction, however, is growing more important with the increasing severity of the requirements of service. Probably the most satisfactory machine for testing wear under lubricated sliding friction is the Derihon machine. This machine consists of a hard steel disk revolving in oil, and against the edge of which is pressed the test specimen. E. Nusbaumer, engineer of the Derihon Steel Works, describes this machine and some tests made with it, in the Proceedings of the Fifth Congress of the International Association for Testing Materials, 1909.

Dry Rolling Friction.—Wear by dry rolling friction is the most important, especially when we consider the vast tonnage of steel in service in the form of rails, wheels and tires.

A machine for investigating wear under dry rolling friction was described by E. H. Saniter in the Proceedings of the British Iron and Steel Institute, 1908. It consists essentially of a revolving test specimen which drives by friction the inner ring of a ball bearing, the outer ring of which is stationary and loaded.

At the Sixth Congress of the International Association for Testing Materials, Mr. Saniter presented a report on "Hardness Testing and Resistance to Mechanical Wear," and gave a summary of the results obtained by Robin, Nusbaumer and himself of the investigation of each of the three classes of wear. The general conclusions of Mr. Saniter were "that while a high Brinell number may be expected to give better wear, there are so many exceptions that its use for the purpose of indicating wearing properties is unreliable as far as the methods of wear testing reviewed are concerned."

The investigations of the author have been confined so far to the third class of wear, dry rolling friction. The machine used is a modification of Dr. Stanton's fatigue testing machine, described by him in the Proceedings of the British Iron and Steel Institute, 1908.

Details of the machine are shown in the illustrations, Figs. 1 and 2. It consists essentially of three case-hardened rollers, $3\frac{1}{2}$ in. in diameter. The two lower rollers are driven by gears, while the third and upper roller, is driven by friction. The upper roller is carried in the lever by which the load is applied to the test specimen. It is possible with this machine to apply a load of 1000 lb. on the specimen. The rollers each have a groove in

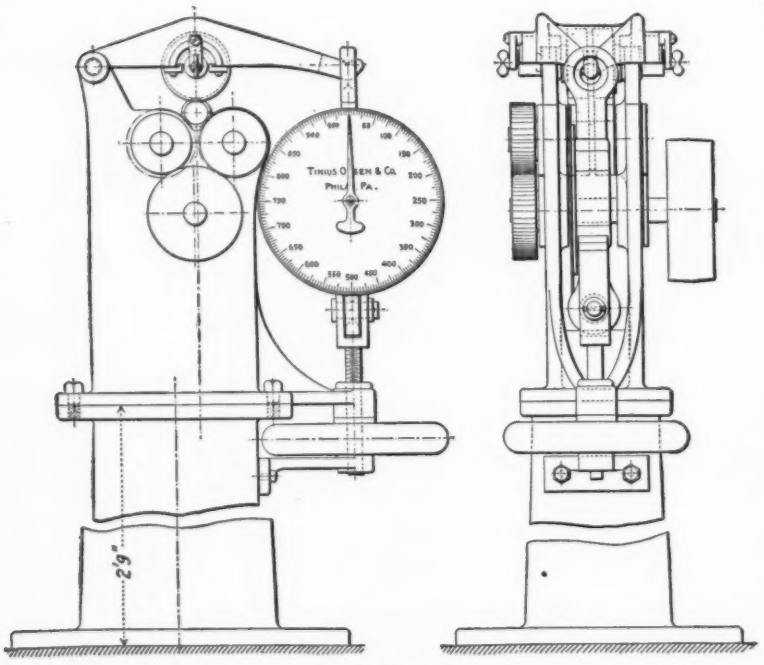


FIG. 1.

the middle, $\frac{1}{4}$ in. wide, to take the corresponding band on the test specimen and so keep it from lateral motion. If the rollers all revolved at a uniform speed the amount of wear on the test specimen would be very slight, practically nothing, as there would be no slippage of the test specimen. In order to accelerate the wear and to approximate as nearly as possible the actual wearing conditions of wheels and rails, the two lower rollers are driven at different speeds to produce a slippage of the specimen.

This is accomplished by having two less teeth in one of the driving gears.

The test specimens are 2 in. long and $\frac{7}{8}$ in. in diameter; the guide band is $\frac{1}{8}$ in. larger in diameter and a scant $\frac{1}{4}$ in. wide. They weigh about 160 grams and can be accurately weighed on a chemical balance to one-tenth of a milligram. The diameters of the specimens which this machine will accommodate vary from $\frac{5}{8}$ to $1\frac{1}{2}$ in.



FIG. 2.

The driving speed of the machine is 1000 r.p.m., and the speed of the test specimen is about 5000 r.p.m.

The usual run before weighing is 100,000 revolutions of one of the driving rollers, corresponding to practically 500,000 revolutions of the test piece. In the tests the results of which are given in Table I, the applied load was 224 lb. or 100 kg. Excepting in the cases there noted, the specimens were all turned from rolled bars $1\frac{1}{8}$ in. in diameter.

TABLE I.—RESULTS OF TESTS ON RESISTANCE OF STEELS TO WEAR.

Mark.	Treatment.	Wear, Milligrams per 1 000 000 rev.	Percentage of						Hardness.		Elastic Limit, lb. per sq. in.	Tensile Strength, lb. per sq. in.	Elongation in 2 in., per cent.	Reduction of Area, per cent.
			Carbon.	Manganese.	Silicon.	Chromium.	Nickel.	Vanadium.	Brinell.	Scleroscope.				
P	None	3 813.2	0.25	0.60	....	....	....	....	134	23	47 000	68 000	33.0	57.3
P-1	825/600° C.	2 436.4	0.25	0.60	....	....	....	....	170	27	58 000	80 000	28.5	67.0
O	None	1 462.0	0.45	0.48	....	....	....	....	156	26	43 000	79 000	28.5	47.5
O-1	825/600° C.	1 334.8	0.45	0.48	....	....	....	....	207	30	71 000	96 000	23.0	57.3
8[1]	None	1 120.5	0.66	0.70	0.27	....	....	....	196	34	63 000	121 000	14.0	19.0
M-1	825/600° C.	1 104.1	0.28	0.61	0.28	....	3.10	....	207	30	87 000	100 000	25.0	67.5
12[1]	825/600° C.	1 079.6	0.75	0.68	0.25	....	....	....	228	38	97 560	144 930	15.0	23.0
E-1	825/600° C.	1 043.1	0.43	1.30	....	....	....	....	223	35	91 000	105 000	23.5	58.6
U-1[1]	825/650° C.	958.0	0.58	0.65	0.20	1.26	....	0.20	248	43	98 000	120 000	19.0	52.8
C-1	829/600° C.	829.8	0.38	0.30	....	1.16	2.08	....	286	47	127 000	134 000	20.0	57.3
K-1	900/600° C.	436.8	0.46	0.90	0.11	1.03	....	0.14	340	54	156 000	163 000	15.0	45.0
F-1	825/600° C.	371.9	0.48	1.15	....	....	....	0.22	262	42	115 000	127 500	18.5	54.7
22[1]	900/625° C.	368.8	0.62	0.62	0.27	0.95	....	0.24	302	43	128 000	147 000	16.5	42.0
Y-1	900/600° C.	367.8	0.28	0.50	0.12	0.96	....	0.22	293	50	137 000	148 000	16.5	46.0
J-1	900/600° C.	261.0	0.46	0.86	0.06	1.02	....	0.22	340	54	162 000	167 500	14.5	49.0
D-1	825/600° C.	230.1	0.42	0.22	....	1.27	2.14	0.26	340	52	156 000	161 150	16.0	53.3

[1] Specimen taken from tire. All others turned from rolled bars, 1¼ in. in diameter.

NOTE.—Under the heading "Treatment," 825/600° C. indicates that the specimen was oil-quenched from 825° C. and drawn back at 600° C.

While the tests show a general decrease in the amount of wear, as the hardness and strength increase, the progression is very irregular, and there are several instances where softer steels show less wear than the harder ones; as for example, steels 12 and E-1, C-1 and F-1.

It is evident that the composition of the steel influences the resistance to wear to a very considerable degree. Robin in his investigations found that nickel, chromium and vanadium each increased the resistance of the steel to wear. Nusbaumer in his tests found remarkable resistance to wear of low-carbon steels with manganese about 1.5 per cent. Saniter on the contrary did not find increased resistance to wear in the case of the few alloy steels he reported, excepting for a high manganese steel of the Hadfield type. His chrome-vanadium and nickel-chrome steels gave greater wear with greater hardness than simple carbon steels of about 0.70 per cent carbon and 0.60 per cent manganese.

The tests which I have made confirm the conclusions of both Robin and Nusbaumer, and also those of actual service experience: that manganese, nickel, chromium, and vanadium have a marked effect on the wearing qualities of steels. Manganese apparently has a greater effect than either nickel or chromium. Vanadium, however, evidently has a much greater effect than either of these three elements, as it requires only a very small percentage to produce a marked increase in resistance to wear. This is very apparent in steels E-1 and F-1, and C-1 and D-1, each of which pair are practically alike, except for vanadium.

As stated in the beginning of this paper, these tests are only a small proportion of those planned, and it is the intention to cover not only a considerable range in composition and heat treatment, but also to study the effect of rollers of different composition and hardness on the rate of wear of the various steels.

DISCUSSION.

Mr. Fowler. MR. GEORGE L. FOWLER.—I have been very much interested in the paper, but, as I understand it, these abrasion tests were made with different metals against a constant rubbing surface. That method, I think, will not always serve to show the relative wearing qualities of the metals under test. In investigating trouble with the wear of gears and pinions some years ago it occurred to me that possibly the combination of the two particular kinds of metal used might have something to do with the abnormal wear. Small slabs were therefore cut from them and rubbed against each other at a constant temperature. The wear of those little pieces was found to in almost exact ratio to the wear of the pinions and gears, both for those that were giving good service and for those that were giving bad service. By simply making such combinations as did not show very much abrasion, we succeeded in doing away with excessive wear. It was a case where one kind of metal could not be so lubricated as to run well against another metal, although under the ordinary abrasion test there was practically no difference between the four or five different kinds of metal that we were using.[1]

Mr. Devries. MR. R. P. DEVRIES.—Where this test is made for testing the wear of steel, I should like to know whether it could be adapted for testing the wear of knife edges of large platform scales and whether it would take into account such a factor as that the load comes on those scales with a kind of surging movement; that is to say, the entire load probably produces some displacement.

Mr. Norris. MR. GEORGE L. NORRIS.—These tests are made primarily to determine wear by dry rolling friction, not lubricated friction as referred to by Mr. Fowler, and especially to get some idea of the wear of tires and wheels on rails. With this object, the machine is arranged so as to get a slippage, such as we get with wheels on rails. While the tests here presented were all made

[1] For a more detailed discussion of this subject by Mr. Fowler, see *Proceedings*, Am. Soc. Test. Mats., Vol. XI, pp. 830–832 (1911).—ED.

with test specimens on case-hardened rollers, it is the intention to test these same specimens on rollers of various materials, such as chilled cast iron and steel of tire quality and rail quality. We want to find if there is any difference between the wear with rollers of these materials and case-hardened rollers. Mr. Norris.

In answer to Mr. Devries' question, I would say that I do not see how this machine could be used for his purpose, because the machine is composed of rollers and the specimens are rolled. Scale-knife edges would have a sharp edge which I presume is subject to breaking down due to a surging action on the plane. For this reason the wear would depend largely, if not entirely, on the hardness and toughness of the steel. For this purpose I understand high-speed steel is very generally used on account of its very high compressive strength and hardness.

MAGNETIC CRITERIA OF THE MECHANICAL PROPERTIES OF A ONE-PER-CENT-CARBON STEEL.

By Charles W. Burrows.

Introduction.

This paper is a report of progress of a portion of an investigation of the relations between the magnetic, electric and mechanical properties of steel, carried on in the laboratories of the Bureau of Standards. In addition to the facilities of the magnetic, mechanical, heat, and chemical laboratories of the Bureau we have had the cooperation of the Pennsylvania Railroad Co., both in the matter of the supply of steel materials and in technical assistance in the person of a representative.

The Problem.

Many of the properties of a piece of steel at a given temperature can be defined in terms of a single numeral. This is true of tensile strength, modulus of elasticity, elastic limit, electric resistance, or heat conductivity. If, for example, the modulus of elasticity of a bar is given, we know at once the elongation that will correspond to any tensile stress less than the elastic limit.

Certain other characteristics, however, are not so simply defined. The magnetic permeability is the most striking of those properties which require for their definition more than a single numeral. The magnetic permeability, or the ratio of the magnetic induction to the magnetizing force, is not a constant for a given material but is a function of the actual induction to which the bar is magnetized. Thus a bar of steel has associated with it, not a single magnetic constant, but rather an infinite number of such constants.

Each one of these magnetic constants is comparable to such a mechanical constant as tensile strength or the Brinell hardness, in that it is a function of the chemical composition,

the mechanical treatment, and the heat treatment. The magnetic behavior of a bar of steel is determined by its chemistry and previous history. These in turn determine not only the magnetic properties, but all other characteristics as well. Furthermore, all the data available for material that is reasonably homogeneous seem to indicate that this is a one-to-one correspondence; that is, a given complete set of magnetic characteristics corresponds to one and only one set of other characteristics. If this one-to-one correspondence exists there is no theoretical reason why all the physical and chemical properties of a bar of steel should not be expressed in terms of its magnetic constants.

The problem is closely analogous to that of the mathematician who attempts to express a given analytical function in an infinite power series of a single variable. Practically, it will be possible if the differences between two sets of magnetic data due to small differences in physical or chemical condition are great enough to admit of precise measurement.

From the infinite number of magnetic constants which a given specimen possesses, and the great magnetic sensitiveness which it shows toward slight variations in physical condition, we may well hope to read the complete story of the steel written in magnetic characters.

The task of learning to read in the language of magnetism is very difficult. We must begin with things as simple as possible. Consequently, in the beginning we have restricted ourselves to samples of steel of approximately the same chemical composition and varied only a single condition, the heat treatment.

MAGNETIC CHARACTERISTICS.

The curves of Fig. 1 show a portion of typical induction and hysteresis data for a bar of annealed 1-per-cent-carbon steel and for a bar of hardened material of the same composition. These two curves show characteristics which are more or less typical of the soft and hard states of any steel.

The normal induction curve for the soft steel at initial inductions lies above that for the hard steel. The difference in induction for the same magnetizing force increases up to a

certain point, when the difference begins to decrease. Finally at a magnetizing force of 180 gausses the two curves intersect. Above this point of intersection the harder material shows a higher induction than the annealed material. Similar observations may be made if we consider the differences in magnetizing forces necessary to produce the same induction.

For the hysteresis loop, only the descending portion between the tip of the loop at an induction of 14,000 gausses and the coercive force is shown. The residual induction, or that induction which remains when the magnetizing force is removed, is greater in the annealed bar than in the hardened bar. The

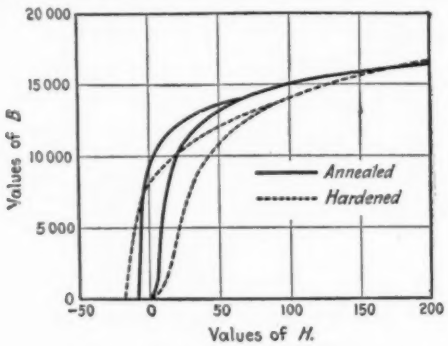


FIG. 1.—Portion of Typical Induction and Hysteresis Curves for Annealed and Hardened Steels.

coercive force, or that magnetizing force which when reversed reduces the induction to zero, is less for the soft material than for the hard. Between the points represented by the residual induction and the coercive force, the two hysteresis loops cross each other.

The mechanical properties of these two steels are as widely different as their magnetic characteristics. The annealed material has a relatively low mechanical strength, a low Brinell hardness numeral, and a low resistance to abrasion. The hardened material, on the other hand, has a much higher mechanical strength, a higher Brinell numeral, and a greater resistance to abrasion. In general the hardened material has all the properties of a correctly treated spring steel.

If we were to draw conclusions from this one set of data, we might say that a high residual induction goes with mechanical softness and a high coercive force goes with great strength. In a great many cases these conclusions hold. However, as these two magnetic constants are not so readily obtained as others, which at first sight seem more promising, they have not been fully investigated as yet. A comparison of the permeabilities of the two induction curves shows that the higher permeability corresponds to the softer material at low inductions and to the material of greater strength at the higher inductions.

Since the engineering requirements demand a combination of toughness and strength, it seemed worth while to examine more fully points along the normal induction curve in the hope of finding a criterion of a suitable combination of this sort.

VARIATION OF NORMAL INDUCTION WITH DIFFERENT HEAT TREATMENTS.

Fig. 2 shows the complete normal induction curves for ten pieces of steel of approximately the same composition, but with different heat treatments. The upper three curves are from unhardened material, including both annealed and unannealed. The lowest curve is from water-quenched or glass-hard material. The remaining six curves are from specimens which were given different treatments, any of which would be considered a satisfactory treatment for a spring steel.

Those specimens which were unhardened form a group distinct from the others. Their curves are not coincident, but lie fairly close together and cross each other at a magnetizing force of about 50 gausses. In some cases two curves will cross more than once. Because of this crossing those curves which are higher initially are usually lower at the high inductions.

The curve for the glass-hard specimen is widely separated from the curves of the unhardened steels and could be distinguished from them very readily if any single point of it was known. If our problem were simply to distinguish between steels which were too soft, due to omission of the proper quenching process, and those too hard, due to such gross treatment as the above, the solution would be very simple.

The middle group of curves represents steels which have

been given treatments that are not open to any very serious objection. They fall into a group which is clearly differentiated from the soft and the brittle steels. For all magnetizing forces below 100 gausses the separation is complete. For higher values, however, the properly treated and the unhardened curves coalesce. Among themselves the properly treated steels show curves that in their initial portions are close together. Above a magnetizing force of about 40 gausses, however, they separate and the individual curves are readily distinguished.

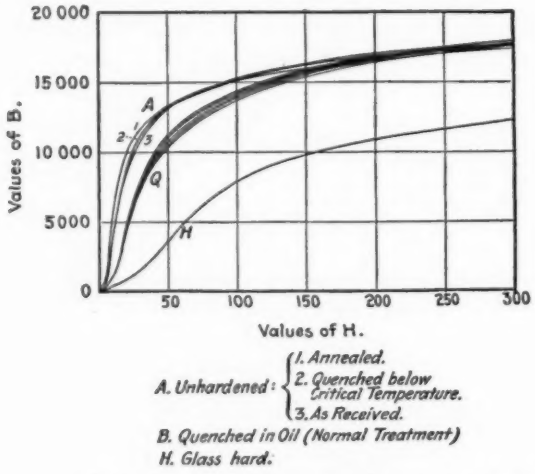


FIG. 2.—Normal Induction Curves for a Spring Steel after Various Heat Treatments.

As far as the curves of Fig. 2 are concerned we might expect to find a satisfactory criterion of the nature of the resulting steel, by considering either the differences in magnetizing forces necessary to produce some moderate induction, as 10,000 gausses, or the differences in inductions at some such magnetizing force as 50 gausses. Many specimens were examined in these ways and the results are quite encouraging.

CHEMICAL COMPOSITION.

Before going further it may be well to examine the influence of slight variation in chemical content.

Fig. 3 shows what differences may be expected between two annealed specimens of steel which, from the engineering point of view, might be considered as having practically the same chemical composition. Two annealed samples of each chemical composition were examined and were found to have practically identical magnetic characteristics. With the two grades differing by about 0.1 per cent carbon we find the higher-carbon steel is the more permeable at the lower inductions and the less permeable at the higher inductions. At a magnetizing force of about 50 gausses however the two curves cross. This crossing would seem to indicate that, for annealed steels of

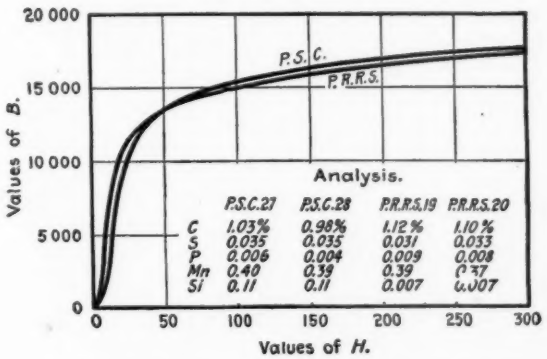


FIG. 3.—Difference between Annealed Specimens of Slightly Different Chemical Composition.

approximately 1 per cent carbon, slight variations in the carbon content have a negligible influence on the induction at a magnetizing force of 50 gausses.

The next three figures show some comparisons between the magnetic induction at a magnetizing force of 50 gausses and certain mechanical properties.

MAXIMUM FIBER STRESS.

In Fig. 4 the maximum fiber stress at the proportional limit is plotted against the induction at a magnetizing force of 50 gausses. The mechanical data were taken by a transverse test and while the numerical values may not be strictly com-

parable with tensile tests, they are quite satisfactory for a comparison. The curve shows several points of interest. The highest induction corresponds to the lowest mechanical strength.

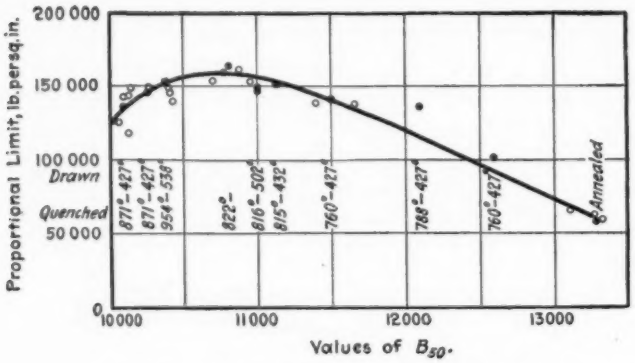


FIG. 4.—Relation between Maximum Fiber Stress in Pounds per Square Inch at the Proportional Limit and Magnetic Induction under a Magnetizing Force of 50 Gausses for a 1-per-cent-carbon Steel.

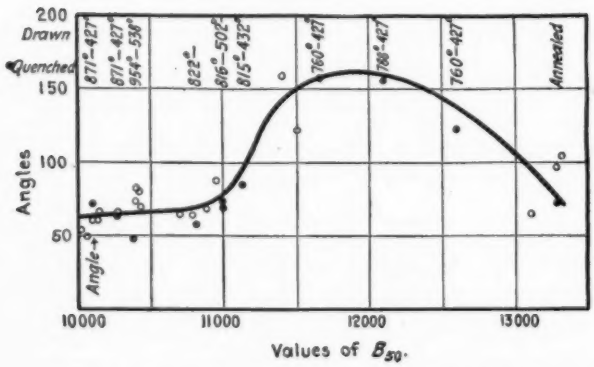


FIG. 5.—Relation between Angle of Cold Bend and Magnetic Induction under a Magnetizing Force of 50 Gausses for a 1-per-cent-carbon Steel.

As the induction decreases the mechanical strength increases up to a maximum value, and with a further decrease in induction the mechanical strength shows a decrease. It is to be noted that the decrease in induction follows very closely with

the increase in quenching temperature, other things being equal. The curve brings out the fact that a given maximum fiber stress at the proportional limit is given by more than one heat treatment, and that the magnetic data distinguish between these conditions.

COLD BEND TESTS.

In Fig. 5 the angles of cold bend are plotted against the magnetic inductions at a magnetizing force of 50 gausses. This curve shows an increase of the angle of bend as the induction decreases, passes through a maximum, and finally decreases

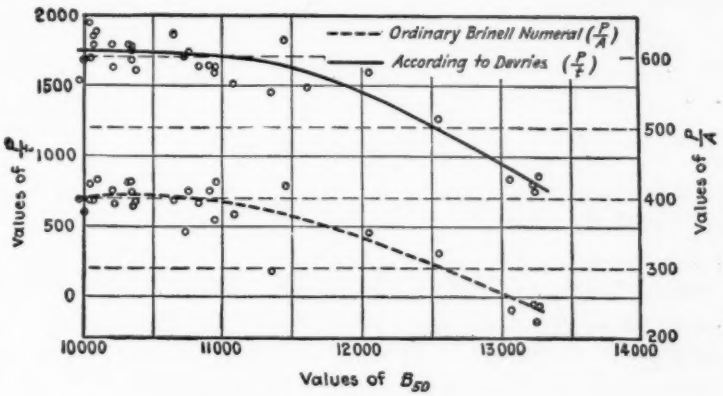


FIG. 6.—Relation between Brinell Hardness and Magnetic Induction under a Magnetizing Force of 50 Gausses for a 1-per-cent-carbon Steel.

with further decrease in induction. The maximum bend occurs at a higher induction than does the maximum fiber stress.

As far as it is safe to generalize from the limited data of Figs. 4 and 5, we may say there is a certain magnetic condition which corresponds to a proper compromise between maximum strength and maximum toughness. If the induction at a magnetizing force of 50 gausses is greater than this value, the material is low in mechanical strength. If the induction is low the material lacks the requisite toughness.

BRINELL HARDNESS.

Fig. 6 shows a comparison between the Brinell hardness numerals and the magnetic data. The broken line gives the

hardness numeral as recommended by Brinell—that is, the quotient of the total pressure on the sphere divided by the area of the spherical indentation. The solid curve represents the numeral according to the method of Devries, using the quotient of the total pressure divided by the depth of indentation.[1]

The wide scattering of the observed points is due in great part to inhomogeneities of the material, as the specimens frequently showed a greater hardness near the edge than on the middle portions of the sides, and also showed variations along the length of the specimen. Because of these inhomogeneities, determinations of the hardness were taken at different parts of the bar and the average value used in plotting. These curves show a general increase in hardness accompanying a decrease in magnetic induction.

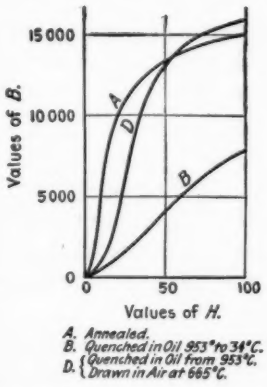
SPECIAL HEAT TREATMENTS.

From the data thus far presented it is evident that at least a partial separation can be made of the material which has been properly heat-treated from that which has not been so treated. The data from which Figs. 4 and 5 were obtained show variations from the mean curve as drawn greater than desirable. Variations may be expected due to inhomogeneity of the heat-treated test specimen, or to accidental errors in the measurements. All of the test specimens examined were of rectangular section with sharp edges. In water-quenched specimens the maximum hardness is found at the edges, and we believe that in many cases these edges exercise a marked influence upon the magnetic and mechanical characteristics. With round bars, or flat bars with rounded edges, we would expect more concordant results. All measurements, however, were carried out very carefully and where possible they were verified, so that the number of accidental errors has been reduced to a minimum. Inhomogeneities were found to exist especially in those specimens which show the widest divergence from the mean curve.

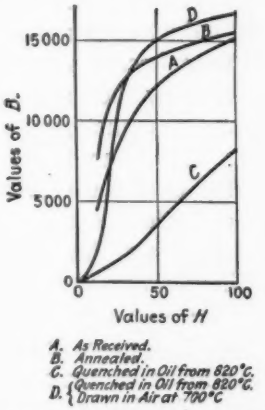
Another possibility is that the criterion which we have

[1] A comparison of these methods is given in the Technological Papers of the Bureau of Standards, No. 11, "Comparison of Five Methods used to Measure Hardness," by R. P. Devries.

tentatively assumed is not the best one. We choose as our criterion the magnetic inductions at a magnetizing force of 50 gausses. Quite possibly some other criterion would be better. For this reason we have in general throughout the course of the investigation obtained data in regard to the inductions at various magnetizing forces for each specimen. The resultant steel product that we wish to examine is a complicated one and has a number of qualities which must be controlled. Because of this it may be better to use not one but several of the possible magnetic constants. This broadening out of the magnetic test



(*a*) 1-per-cent-carbon Steel.



(*b*) 0.8-per-cent-carbon (1-per-cent-manganese) Steel.

FIG. 7.—Effect of Special Heat Treatment on Magnetic Properties of Steels.

might have been suggested from the curves of Fig. 3. This figure shows that slight variations in carbon content of the annealed samples produce little or no effect at a magnetizing force of 50 gausses, but that very considerable effects are produced at higher or lower inductions. The preceding data were obtained with materials which, while they undoubtedly contained some inhomogeneities, were uniform in general. If the material has been given a heat treatment, which results in an inhomogeneity of structure between the core and the surface of the material, further investigation is required. In the remaining two figures, the material of the curves marked *D* are open to such a suspicion. The materials in the condition represented

by the curves behave mechanically as though they consisted of a tough core surrounded by a strong outer layer, quite analogous to case-hardened material.

The material of Fig. 7 (*a*) was given a rather unusual treatment and yields data that do not fall on the mean curves of mechanical constants previously given. The curve for the material in the annealed condition is perfectly normal. The same is true of the material after quenching. This curve corresponds very closely to that for the hardened material of Fig. 2. After drawing the material at the unusually high temperature of 565° C., it shows several quite marked characteristics. The initial induction is much lower than the annealed, but at higher inductions becomes much greater than that of the annealed. Mechanically the material is strong and tough. The maximum fiber stress is much greater than would be indicated by the curve of Fig. 4. From this figure and other similar data it seems probable that the ordinary hardness and mechanical strength will be in the inverse order of the inductions at some magnetizing force less than 50 gausses, while the toughness will be in the direct order of the inductions at some force greater than 50 gausses—possibly as high as 100 gausses.

Fig. 7 (*b*) gives further data along the same line. This material is a lower-carbon steel and contains about 1 per cent of manganese. The lower portions of the curves arrange the specimens in the order of their mechanical strength. At magnetizing forces above 30 gausses the specimens have the same order in magnetic induction and in toughness.

Whether the peculiar mechanical properties of the materials just mentioned are due to a strong tough homogeneous material, or to a tough interior and a strong exterior, the magnetic curves show sufficient individuality to distinguish material so treated from similar material treated otherwise.

CONCLUSION.

I have presented enough data to show that it is practically possible to distinguish between steel which has been properly prepared and that which has been improperly prepared. The magnetic properties are very sensitive to differences in mechanical structure, and from a knowledge of the complete magnetic

data the mechanical properties can undoubtedly be foretold. There is strong probability that only a limited portion of the magnetic data will be sufficient. The present investigation has not progressed far enough to enable one to say just how little data will be sufficient or what constants will be most suitable. These questions cannot be answered until after much experimentation.

In closing, let me say again that this paper is but a report of progress to let the members of the Society know that this investigation is being actively carried on and to encourage the work of others along similar lines.

RAIL FAILURES AND THEIR CAUSES.

By M. H. Wickhorst.

Recent years have been active ones in the matter of investigations of rail failures by the railroads, the rail manufacturers and public service bodies, and it is proposed in this paper to consider our present information concerning the nature of the failures and their causes.

From the standpoint of the visible condition of the failed rails most of the rail failures may be divided into three classes, as follows:

1. Crushed and split heads;
2. Broken rails (square and angular breaks);
3. Broken bases (crescent breaks).

In addition to these, there are other failures occurring in smaller numbers, such as "cracked webs" (horizontal longitudinal cracks through the web) and "transverse fissures" (transverse internal cracks in the interior of the head).

Statistics concerning the rail failures occurring in the United States have been published for several years by the American Railway Engineering Association, and in Table I are given a few figures covering rail failures for the year ending October 31, 1911.[1] The tons are long tons of 2240 lb. and represent the tons of new rail laid.

It will be noticed from this table that the failures in 1911 per 10,000 tons of new rail laid were 31.0 for Bessemer steel, 20.7 for open-hearth steel, and the average of all rails was 29.0.

On the basis of number of rails, there was one failure per 891 Bessemer rails, one failure per 1234 open-hearth rails, and one failure per 941 rails of both steels. This suggests that open-hearth steel is less liable to failure than Bessemer steel, but on the other hand it is probably true that the open-hearth

[1] *Bulletin No. 147*, Am. Ry. Engrg. Assoc., Vol. 14, p. 392 (July, 1912); also, *Proceedings*, Am. Ry. Engrg. Assoc., Vol. 14, p. 392 (1913).

rails were in general of more recent manufacture and probably also contain more of the newer sections. The table cannot therefore be said to be conclusive in its indications in this respect.

The table shows us that there was one failure per 941 rails, but we seem not to have general information of all the failures occurring during the full period of service of a lot of rails. As-

TABLE I.—RAIL FAILURES IN 1911.

	Bessemer.	Open-hearth.	Total.
Tons of rails represented	10 088 706	2 600 008	12 688 714
Number of rails based on 30-ft. lengths	27 866 348	6 622 736	34 489 084
Number of failures:			
Broken	8 165	1 786	9 951
Head	17 761	2 260	20 021
Web	2 450	515	2 965
Base	2 898	806	3 704
Total	31 274	5 367	36 641
Failures per 10 000 tons:			
Broken	8.1	6.9	7.9
Head	17.6	8.7	15.8
Web	2.4	2.0	2.4
Base	2.9	3.1	2.9
Total	31.0	20.7	29.0
Percentage of failures:			
Broken	26	33	27
Head	57	42	55
Web	8	10	8
Base	9	15	10
Total	100	100	100
Number of rails for each failure	891	1 234	941

suming, for the purpose of forming some idea of the order of magnitude of the average total failures in a lot of rails, that the average life of rails is 8 years, the total failures per lot of rails would average about one failure per 118 rails or something under one per cent.

While the American Railway Engineering Association statistics above referred to indicate an improvement in the general failure performance from year to year in the last three

years that they have been kept, we still hear of occasional lots rolled in recent years that give very poor service. As an example may be mentioned a lot of 2500 tons of 80-lb. A. S. C. E. Bessemer rails rolled in September, 1909, and placed into track in October, 1909. Up to May, 1912, or in a period of service of 2½ years, there were 510 failures classified by the trackmen as follows:

Crushed head and flow of metal	243
Split head	93
Split web	89
Broken	81
Broken base	4
Total	510

This would be 2040 failures per 10,000 tons; or figured on the basis of 30-ft. lengths, there would be one failure in each 13.7 rails in 2½ years from the time the rails were put into service. I am advised that since May, 1912, other rails have been removed from track and still others at this writing (March, 1913) are developing a condition that will necessitate their removal. Thus far about 7 per cent of this lot of rails have been removed from service on account of failures, mostly of the head, and it seems probable that finally the number may amount to 10 per cent or more. This type of failure, as will be explained, is to be attributed to the interior condition of the ingot from which the rail was rolled, described as segregation and its accompanying conditions.

CRUSHED AND SPLIT HEADS.

Head failures are the most numerous and most of these may be described as crushed or split heads. This failure consists of an internal crack in the head running lengthwise of the rail anywhere from a foot or two to several yards in length. The external appearance may show only a crushing of the head; but when broken, the rail will show a crack in the interior of the head running lengthwise of the rail. A specimen of this type of failure is shown in Fig. 1. This kind of failure is confined almost entirely to metal showing considerable internal segregation of carbon, phosphorus and sulphur, attended more or less with laminations

and slag seams[1]. Under wheel loads, the top of the head flows sideways and if the interior metal cannot likewise flow sideways due to internal flaws or due to brittle material in the interior, it develops a crack which grows and later forms a split head, the crack generally coming to the surface at the under side of the head at its junction with the web. Frequently the crack extends downward into the web and comes to the surface at the side of the web, and then the trackman is apt to report



FIG. 1.—Sample of Split Head Rail.

the failure as a web failure, whereas in reality it was a head failure.

Split heads may thus be said to be due to lack of transverse ductility in the interior of the head, due mostly to segregation.

BROKEN RAILS.

The next largest class of rail failures is that called "broken" rails, including square and angular breaks; that is, the rail breaks through the whole section more or less vertically. This

[1] *Proceedings*, Am. Ry. Engrg. Assoc., Vol. 12, Part 2, pp. 469–493 (1911); also, "Studies of Failed Rails," by W. C. Cushing, *ibid*, pp. 230–384.

type of failure is most predominant in winter, particularly in severely cold weather, and may be termed "winter disease" of rails. The severe winter of 1911 and 1912 brought out a very abundant crop of such failures on the northern roads. An examination of the fractures of such rails shows that the fracture is upward through the section; that is, it starts from the base, and the rails also show longitudinal cracks or seams at the bottom of the base. Mr. H. B. MacFarland, Engineer of Tests, Atchison, Topeka and Santa Fe Railway Co., has made an interesting report[1] in which he shows that most "broken" rails were



FIG. 2.—View of Base of a "Broken" Rail, showing Seam in Base and "Scalloped" Break across Base.

accompanied by half-moon base fractures, which observation has also resulted from other investigations. Probably the most prominent feature of the appearance of most "broken" rails, is what may be called the "scalloped" fracture across the bottom of the base; that is, the fracture is not straight across the base but one side is concave or re-entrant with a sharp corner, while the other side is pointed and dovetails into it. The concave side of the fracture also generally shows a seam at the bottom of the base. A view of the bottom of a typical "broken" rail is shown in Fig. 2.

[1] *Bulletin No. 147*, Am. Ry. Engrg. Assoc., Vol. 14, p. 315 (July, 1912); also, *Proceedings*, Am. Ry. Engrg. Assoc., Vol. 14, p. 315 (1913).

SEAMS IN BASE OF RAIL.

Rails frequently contain longitudinal surface seams, and in this connection a study of the behavior in the drop test of a rail containing seams in the bottom of the base is important. These base seams vary in depth from 0.01 to 0.1 in. and occasionally deeper. Fig. 3 gives a view of the vertical fractured surface of a piece of flange broken off from a new rail. showing a deep seam at the bottom of the base.

When tested in the drop test in the usual manner, the rail ordinarily breaks at or near the place where hit by the tup due to exhaustion of the longitudinal ductility of the part in tension. Occasionally, however, when tested with the base in tension,—

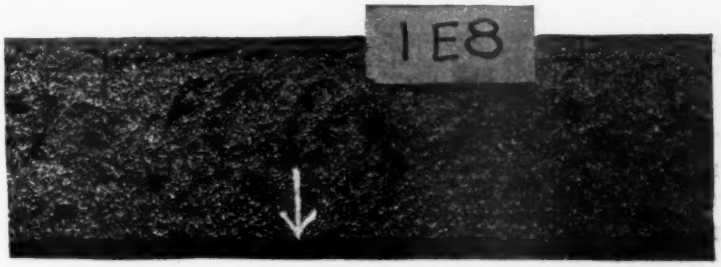


FIG. 3.—Vertical Longitudinal Fracture of Flange, showing Longitudinal Seam in Bottom of Base of a New Rail.

that is, with the base resting on the supports,—the fracture occurs near one of the supports. A view of the base of a rail broken in this manner is shown in Fig. 4. This was a 100-lb. rail broken in the drop test with the base in tension, supports 3 ft. apart, and given one blow of a 2000-lb. tup from a height of 20 ft. The impression left on the base by the support was chalked to show up more clearly in the illustration and it will be noted that the permanent impression was confined mostly to the middle third of the width of the base. It will be noted that the pressure of the rail on the support caused some side spread of the base at this place, which in turn opened up a seam. A piece of the flange broke, and a fracture occurred through the whole section 3½ in. from the support, as a secondary break. The failure of this rail occurred long before the longitudinal

ductility was exhausted and may be considered as due to insufficient transverse ductility at the bottom of the base, because of the presence of seams.

When tested with the head in tension, the result is of a similar nature if there is a seam in the base at the place where

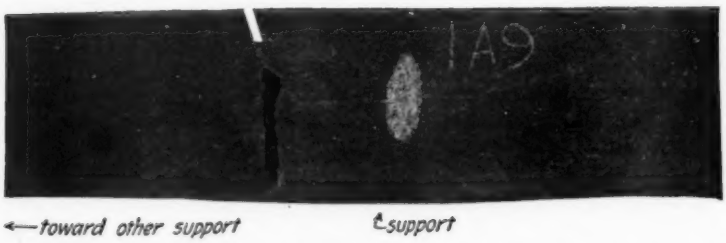


FIG. 4.—Sample of Rail Tested with the Base in Tension in the Drop Test, showing how a Seam in the Base was the Origin of the Failure.

struck by the tup. Fig. 5 shows the base of a rail tested in this manner. Here again the blow of the tup caused a side spread of the metal of the base where struck, which in turn opened up a seam causing a failure from the top side, not due to exhaustion of the longitudinal ductility of the head.



FIG. 5.—Sample of Rail Tested with the Head in Tension in the Drop Test, showing how a Seam in the Base Opened under the Tup, causing the Base to Split.

BASE FAILURES.

About ten per cent of all rail failures, according to Table I, are base failures, mostly half-moon or crescent-shape pieces broken out of the flange. These occur mostly at ties and appear also to be largely attended with seams in the base. The origin of the failure in this type, as with "broken" rails, thus appears

to be the seams in the base and these two types should therefore be classed together as regards cause of failure.

OTHER FAILURES.

A type of failure that has attracted considerable attention in recent years, is the "transverse fissure" or "oval spot" in the interior of the head, an example of which is shown in Fig. 6.

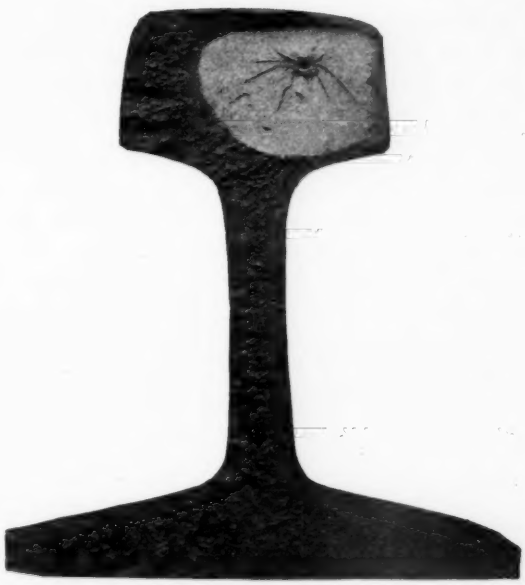


FIG. 6.—Samole of "Transverse Fissure" in Head of Rail.

This type was first brought into prominence by a report by Mr. J. E. Howard, of the Bureau of Standards, on a rail ascribed as the cause of a bad wreck on the Lehigh Valley Railroad at Manchester, N. Y., on August 25, 1911.[1] Mr. C. D. Young, Engineer of Tests of the Pennsylvania Railroad Co., has also presented an interesting report of his investigations of some failures of this type that occurred on the Pennsylvania Railroad.[2]

[1] "Interstate Commerce Commission Report on Lehigh Valley Railroad Wreck at Manchester, N. Y., Aug. 25, 1911." *Railway Age Gazette*, Feb. 16, 1912, p. 280.

[2] *Bulletin No. 151*, Am. Ry. Engrg Assoc., Vol. 14, p. 413 (Nov., 1912); also, *Proceedings*, Am. Ry. Engrg. Assoc., Vol. 14, p. 413 (1913).

While these reports contain valuable data and good suggestions, the writer feels that a full explanation of the cause of this type of failure has not as yet been worked out, which necessarily must precede effective action for remedying the trouble. This kind of failure is occasionally followed with disastrous results, but fortunately occurs only in small numbers except perhaps under some special conditions.

Another type of failure that constitutes a small percentage of the total failures is the "cracked web," in which the web is cracked through from side to side running lengthwise of the rail; but here again the writer is not aware of a final explanation having been worked out.

SERVICE CONDITIONS AS CAUSES OF FAILURES.

Wheel loads have been increasing ever since the beginning of railroads and the tendency seems to be to still further increase them, at any rate as regards the average wheel loads. The heavy wheel loads have been given as the cause of rail failures. While it is true that the loads are heavy, it is also true that failures are confined to what may be called defective rails, and that most rails stand up under the service. The failures classified as crushed and split heads have for some time been recognized as due to defective metal; and although "broken rails" eluded us for a while, as attributable to the material, we may say these also are to be ascribed to defective material although not defective metal.

Bad counterbalance, flat wheels and other abnormal conditions kink good rails and throw them out of line, although, of course, the defective rails are more promptly found by such abnormal conditions. A rail tested in the drop test will ordinarily stand a bend of several inches in a span of 3 ft. Of course the railroad that persists in bending and kinking its rails will soon have an unrideable track for satisfactory service. It seems to be true that such matters as weight of rail or design of section are of but small importance in the matter of rail failures, but are rather matters more concerning the rideability of track and cost of maintenance.

REMEDIES.

The above part of this paper deals with diagnosis and I think we have now arrived at a point where we may feel considerable confidence that we have the correct diagnosis of the causes of most of the rail failures. About 50 per cent are ascribable to low transverse ductility of the interior of the head due to segregation (and its attendant conditions), and traceable to the interior condition of the upper part of the ingot. About 40 per cent are ascribable to low transverse ductility at the bottom of the base, due to the presence of longitudinal seams at the bottom of the base, and probably the origin of these seams is to be looked for in the rolling of the steel. This leaves about 10 per cent not yet diagnosed. What remedies will finally be applied I, of course, cannot say, but below are given some thoughts as to the directions in which betterments are to be looked for.

According to Table I, 55 per cent of the rail failures of 1911 were head failures and 8 per cent were web failures, and as already indicated most of these may be classified as crushed and split heads, attributable to excessive segregation in the interior of the ingot, together with the conditions which ordinarily attend such excessive segregation, such as sponginess and an abnormal softness of the steel at the outer part of the rail section around the segregated region of the rail. Thus, it appears that the remedy for about 50 or perhaps 60 per cent of rail failures, is to be looked for in a reduction of segregation below the point where it causes a brittleness of the interior metal of the rail. The condition of sponginess is worst at the top end of the rail bar, but the segregation reaches its worst condition at a varying distance from the top end—ordinarily about 15 per cent of the weight of the ingot from the top end of the ingot—and varies in degree from harmless segregation to a condition sure to result in bad service of the rail. It seems to be well established that well-deoxidized, quiet-setting steel has not the concentrated segregation found in other steel and is free from sponginess, but the central pipe extends farther downward into the ingot. The main cause for head failures is, however, the excessive segregation, and to avoid this requires a sufficient discard from the top of the ingot, or steel treated with sufficient silicon, titanium or aluminum. It is usual for rail specifications

to put a maximum limit of 0.20 per cent on silicon, but the author's work[1] indicates it is necessary to have 0.25 per cent or more silicon in the steel in order to obtain its full influence in reducing sponginess and segregation. When titanium is used, 0.1 per cent or more of metallic titanium is probably the proper amount with which to treat the steel. Talbot recommends aluminum[2] used in amounts of 2 oz. per ton or about 0.006 per cent.

It seems that we must come to a well-deoxidized dead-quiet-setting steel, but then we have a deep pipe to deal with when the steel is cast in the usual manner into ordinary open-top iron molds. There has been recently, and still is, considerable experimental activity toward overcoming this condition and the next few years may see a practicable and economical solution of this problem of pipe, available on a large working scale. Hadfield recommends a sand top to the mold and special arrangement to keep the top metal liquid till the bottom of the ingot has set. Talbot recommends a pre-rolling or liquid compression, and a number of other means have come to public attention lately. Possibly, also, some improvement may be obtained by closer attention to the details of the present casting process; or, again, satisfactory uses may be found for the upper part of the ingot for other purposes. The conclusion seems to be emerging, however, that for rails, a well-deoxidized, quiet-setting steel must be used, in order to avoid excessive segregation and to obtain rails with a uniform hardness at the wearing surface in the several rails of an ingot. A solution of the ingot problem means the prevention of about half of the failed rails of the country.

As indicated above, about 40 per cent of the rail failures are traceable to a longitudinal seam at the bottom of the base. The seam does not show on the new rail and cannot be discovered by inspection, but shows up when the failed rail is examined. We have very little satisfactory information as to the origin of these seams (although they seem to be produced in the rolling),

[1] "Influence of Silicon on Open-Hearth Ingots and Rails," *Bulletin No. 151*, Am. Ry. Engrg. Assoc., Vol. 14, p. 507 (Nov., 1912); also, *Proceedings*, Am. Ry. Engrg. Assoc., Vol. 14, p. 507 (1913).

[2] "The Production of Solid Steel Ingots," Am. Inst. Min. Engrs., New York meeting, Feb., 1913.

but the matter is being studied more critically and we hope in the course of time to have more satisfactory knowledge of the subject.

CONCLUSION.

In conclusion, we may say (considering the number of failures) that about 50 per cent of the rail-failure problem consists of obtaining sound metal of fairly even composition, and about 40 per cent consists of so rolling the metal into rails as to avoid seams in the bottom of the base. The earnest activity and the cooperation between all interests to produce improvement in the matter of rail failures is such that we may well be hopeful of the future. The steel mills have freely offered the facilities of their works to the railroads for experimental work, and I in particular wish to acknowledge the uniformly kind treatment accorded me in my work at the various mills. As a still further improvement of the general situation, I would urge upon the metallurgists and other officers of the steel mills that they be more forward in publicly presenting the results of their studies and investigations. And finally, may we ever keep in mind those inspiring words of Longfellow:

Let us, then, be up and doing,
With a heart for any fate;
Still achieving, still pursuing,
Learn to labor and to wait.

DISCUSSION.

Mr. Carhart.

MR. P. E. CARHART.—Dr. Dudley made the statement some years ago that rail failures were largely a matter of geography. I notice that Mr. Wickhorst has condensed in a few figures the failures in the United States, or at least those of a majority of the railroads. Now, it seems to me that Mr. Wickhorst might go a great deal further with that, with interest to all of us. Believing Dr. Dudley's statement to be correct, I would suggest that Mr. Wickhorst take the roads in the warm climate and segregate them as one unit, those in colder climates as another unit, those in the Rocky Mountains and the Allegheny Mountains, where there are heavy grades and sharp curves, as another unit, and the trunk lines, where the traffic and wheel loads are heavy, as another unit. I think we would then begin to arrive at a clearer idea as to the cause of rail failures.

I think Mr. Wickhorst might have gone further in his statement as to wheel loads and rail sections, and I hope that he will do so later on, for I think these matters are of vital importance.

Mr. Hibbard.

MR. HENRY D. HIBBARD.—Mr. Wickhorst says that "Hadfield recommends a sand top to the mold and special arrangement to keep the top metal liquid till the bottom of the ingot has set." It would be more accurate to say that Hadfield uses and recommends the sand top, etc. I believe that Hadfield's firm has made about 25,000 tons of ingots by that method, with great success.

As far as surface seams are concerned, there are a number of ways in which they can be caused, and I believe that if Mr. Wickhorst follows the matter up he will find that some of them come from skin blowholes which are near the surface of the ingot and are burned into in the heating operation. Thus they become filled with oxide of iron and are drawn out and elongated in the rolling operation, so that seams result.

Mr. Onderdonk.

MR. J. R. ONDERDONK.—I want to make a remark in regard to Mr. Carhart's statement about failures of rails being due to

geographical location. We have to run the railroads in the East, West, North and South and there is only one other way to prevent the breakage of rails that they are furnishing us to-day, and that is to stop running traffic over them. **Mr. Onderdonk.**

MR. N. G. PETINOT.—I note in the conclusion of Mr. Wickhorst's paper that a well-deoxidized quiet-setting steel is required in order to avoid excessive segregation in rails. Figs. 1 and 2 **Mr. Petinot.**



C = 0.70 P = 0.024
Mn = 0.735 S = 0.024
Si = 0.170

White-Souther Endurance Test = 2,689,000 rev.

FIG. 1.—Plain Open-hearth "A" Rail.

show two sulphur-prints of sections of rails made a few weeks ago. Both are open-hearth "A" rails of about the same composition, made the same day in the same mill—and consequently under as nearly as possible the same conditions. The one shown in Fig. 2, however, has been treated with 0.10 per cent of metallic titanium as deoxidizer, using for that purpose some 15-per-cent ferro-carbon-titanium, the only deoxidizer known

Mr. Petinot. which, when added to steel, passes away without leaving in the steel any product of its oxidation.

The silicon has been intentionally lowered in the steel treated with ferro-carbon-titanium to avoid a too deep pipe in the ingot.

The sulphur-print in Fig. 1, showing segregation. has not



C = 0.74	S = 0.028
Mn = 0.682	Si = 0.100
P = 0.25	Ti = traces

White-Souther Endurance Test = 25,281,800 rev.

FIG. 2.—Open-hearth "A" Rail Treated with 0.10 per cent of Titanium.

been chosen as a curiosity, but is a typical example of eighty per cent of our open-hearth "A" rails actually in service, of which some are even worse. I have hundreds of sulphur-prints of sections of rails showing still more contrast between treated and untreated rails.

The diminishing of segregation by proper use of titanium is checked by chemical analysis; an example is given in Table I.

TABLE I. Mr. Petinot.

Elements Considered.	Heat No. 1223, untreated.				Heat No. 7225, treated.			
	Top of Head.	Center of Head.	Flange.	Limit of Segregation.	Top of Head.	Center of Head.	Flange.	Limit of Segregation.
Carbon, per cent.....	0.64	0.75	0.73	0.11	0.76	0.77	0.77	0.01
Manganese, per cent....	0.784	0.901	0.790	0.117	0.744	0.810	0.757	0.066
Phosphorus, per cent....	0.019	0.026	0.020	0.007	0.019	0.018	0.018	0.001
Sulphur, per cent.....	0.032	0.050	0.038	0.018	0.034	0.035	0.035	0.001
Silicon, per cent.....	0.137	0.145	0.145	0.008	0.090	0.092	0.089	0.003

The same diminishing of segregation could be shown on steel deoxidized with ferro-carbon-titanium, of various carbons contained used for axles, forgings, etc.

MR. ROBERT JOB.—I have been interested in Mr. Wickhorst's statement regarding the probable cause of the formation of base seams, and I think it would be of great interest to us all if some of the manufacturers present were to give their statement as to what they consider the cause of base seams. Mr. Job.

MR. W. R. WEBSTER (*by letter*).—Mr. Wickhorst has made a very strong plea for better rail steel. In this he will be most heartily supported by the Society and its committees, especially in the matter of greater discard from the ingots to get rid of piping and segregation. We have struggled with this problem for years, with little or no results, when Bessemer steel was at first used almost exclusively: but now with the large and increasing output of open-hearth steel for rails, it is becoming merely a commercial proposition. Some engineers are willing to pay an extra price for 25 per cent or more of discard, while others prefer using the top rails in places where the service conditions are not severe. Mr. Webster.

For some years rails have been stamped to show their location in the ingot, and while it is true that most of the failures are in rails from the upper portion of the ingot, yet a large number of rails from the middle and bottom half of the ingot have also failed in service with the characteristic fractures referred to by

Mr. Webster. the author. It is fair to assume that a large portion of the failures from the bottom of the ingot was not due to piping or segregation, although many of them may have been caused by the transverse weakness of the rail due to seams in the steel and other causes. The writer has covered this matter at length in a recent discussion of the report of the Committee on Rail of the American Railway Engineering Association, which will appear in the July Bulletin of that Association, so it is not necessary to go into it further at this time.

Some of the open-hearth steel from the bottom of the ingots rolled into rails which have failed, is as good as any steel used for forgings, boilers, bridges, or other important work, and it is therefore a little premature and hardly fair for the author to assign the cause of 90 per cent of all rail failures to the quality of the steel used and to say:

> "It seems to be true that such matters as weight of rail or design of section are of but small importance in the matter of rail failures, but are rather matters of rideability of track and cost of maintenance."

This is a very simple and easy way to dispose of the section and weight of rail best suited to give the traveling public the protection they should have with the present heavy rolling stock and high speeds, provided it is intended to treat only one side of this important subject, and not to consider the additional safety that could be secured by the use of heavier rail rolled to improved section. The writer has gone into these matters very fully in the discussion referred to above, and has quoted therein from the report of the Committee on Rails and Equipment of the National Association of Railway Commissioners, presented at their twenty-fourth annual convention last fall. Their report is most comprehensive, temperate in tone, and treats fairly both sides of the question. The subject is covered very thoroughly, as is shown by the attached summary of the report, to which are added their conclusions that the desired results can be obtained without government supervision, and recommending an effective continuation of the government tests on rails and rail ingots, which was begun some years ago at the Watertown Arsenal under a committee of engineers, all of whom were members of the American Society for Testing Materials. The

plan suggested is to continue the work on the same general lines as before, with the assistance of a committee of engineers representing both the consuming and manufacturing interests. This work should have the support and cooperation of the Society and its committees in every possible way. Mr. Webster.

The writer would also like to ask Mr. Wickhorst if it was not assumed when the American Society of Civil Engineers' rail sections were adopted in 1892, that the quality of the steel would be the same in rails of all weights, and that no attention was paid to the effect of the heat treatment of the steel on the heavier sections, in the way of internal rolling strains from different finishing temperatures of the head and flanges; also, if decided improvement has not been found in recent years in rails rolled with heavier bases. This being the case, why should we be satisfied with the present rail section notwithstanding the fact that there were 36,641 rail failures in 1911? As a matter of fact, does not the thin web, connected to the wide thin head, exert a wedge action tending to split the head when the load is carried on the outer edges due to false flanges or worn wheels? Would not this longitudinal splitting of the head be largely overcome by using a rail having a much deeper head, connected to a thicker web with large fillets, which would act as brackets and thus prevent the wedge action? It is well recognized that the transverse strength in the head of the rail is not more than seven-tenths to eight-tenths of its longitudinal strength, and it is doubtful if with the soundest steel we can get as good transverse strength and ductility as desired. Therefore, why not use a little common sense and design our rail heads by using more of the weaker steel in the overhang of the head with good supporting brackets, with a view of removing the cause of most of the failures from crushed and split heads?

The thin web in our present sections also acts as a wedge on the thin wide flanges, causing them to open up longitudinally if there are any defects in the steel. Of course we want better metal, freedom from longitudinal seams and overlaps, but we also want a much thicker web connected to much thicker flanges by large fillets, which will carry the load and act as braces. These changes of the web and flanges would go a long way towards overcoming the present troubles from broken bases.

Mr. Webster.

The present sections do not allow rolling the steel in a manner suited to get the best results from it, and no matter how perfect the steel may be in the future, there will always be trouble from internal rolling strains in the heavier rails if the present sections are used. But, by putting much more metal in the web and flanges, with deeper heads and large connecting fillets, rails can be rolled which will come from the rolls almost straight, and in requiring very little straightening, avoid a very serious process to which many of our rail failures are due. In addition to this, such rails could be rolled throughout at much lower temperatures; the steel will be tougher and the rails will wear better than our present sections and will not require as much carbon. If necessary, however, higher carbons could be used with the better control of the rolling temperatures and much lower finishing temperatures.

In conclusion, the writer would say that instead of the section and weight of rail being a trivial matter that can be passed over as being of little or no importance, it is of as much if not more importance than the quality of the steel used within the present commercial conditions of manufacture, and that it will only be by a decided change in our rail sections and increased weight that we shall get satisfactory rails to meet the present heavy wheel loads and conditions of service, which are much more severe than those in any other country.

SUMMARY OF REPORT OF COMMITTEE ON RAILS AND EQUIPMENT AT THE TWENTY-FOURTH ANNUAL CONVENTION OF THE NATIONAL ASSOCIATION OF RAILWAY COMMISSIONERS.

This committee was appointed to study the subject of rails and railway equipment, to report upon the advisability of government inspection and of legislation to reduce failures, and to consider other questions related to this subject.

Because of the impossibility of covering the entire ground with thoroughness, the committee decided to confine its attention almost exclusively to rails. The study of rail failures and of possible improvements is complicated by various uncertain elements, such as quality of material, weight and speed of locomotives and cars, and track conditions. Experts differ widely, and it has been impossible for the committee to weigh all of the conflicting evidence available or to question experts to the extent necessary to reach

positive conclusions. Statements as to causes of failure and suggestions for improvement are therefore advanced as topics for discussion rather than as final conclusions. **Mr. Webster.**

The suggestions of the committee are given in detail in the report and are summarized as follows:

1. Present rail-failure problems are similar to those of the past. Recent breakage of steel rails develops questions similar to those which were caused by the breakage of iron rails. The problems of rail failure and wear are continuous ones, which have always been serious and will probably always remain so.

2. The statistics of accidents caused by rail failures are incomplete and unsatisfactory. They indicate, however, that the danger from broken rails is not as great as generally supposed. The statistics for a 10-year period indicate very small percentages of casualty from broken rails, compared with total accidents to passengers and employees. Broken-rail accidents are much less serious as measured by casualties and destruction to property than collisions.

3. No complete statistics of rail failures are available. The best data are that collected by the rail committee of the American Railway Engineering Association.

4. Many of the smaller roads and branch lines have practically no rail failures, and the problem appears to be principally confined to railroads which handle a large tonnage of heavy and fast traffic. For such lines the statistics show that winter rail breakage constitutes the important problem. The number of rail breakages on main lines handling heavy traffic shows that in winter the factor of safety of the rail under prevailing wheel weights and speeds is small, and it is important to consider every improvement which may increase this factor.

5. Main types of rail failures are "split heads," "broken flanges," and "broken rails." The statistics show great variation in the relative number in each of these classes of failures, although the head failures appear to predominate. Some roads have great numbers of broken flanges; others, such as the Harriman lines, have but little "flange failure."

6. Split heads appear to be caused principally by defective material.

7. Broken flanges appear to be the result of transverse weakness in the base of the rail caused by lamination or seams which develop in rolling.

8. Broken rails are caused by defective material and methods of manufacture, defective track, defective equipment, by injury from locomotives slipping, and other accidental causes. Breakages due to these causes are greatly increased by winter conditions and by high speed.

9. The most dangerous form of rail failure appears to be that caused by the development of internal transverse fissures, such as resulted in the Manchester accident. There appears, however, to be very few of such failures, and further investigation is necessary to determine their cause.

10. The principal elements of defective material appear to be defects near the top of the ingot, due to segregation and piping, and flaws scattered throughout the ingot, and caused by blowholes, slag, and various impurities.

Mr. Webster.

11. Rail failures in winter are excessive as compared with summer. In New York State the principal kinds of rail failures for three years averaged about 200 per month for nine months and varied from 364 to 895 per month for the remaining months of January, February and March. This variation was apparently caused by variations in the severity of the winters.

12. Defective track conditions cause many rail failures, especially in the winter. The principal contributing defects appear to be bad surface and poor drainage.

13. Defective equipment causes many rail failures, especially in connection with heavy wheel weights and high speeds. The most serious cause of failures under this head is "flat wheels." Rail failures due to defective equipment are much greater in winter than in summer, and, in connection with defective track and high speeds, probably constitute the principal causes of increased breakage of rails in winter.

14. High-speed schedules in winter in connection with defective track and equipment is the cause of much rail breakage. Train delays in winter are frequent. Fast trains delay local passenger and freight trains, and the pressure to make up time is much increased compared with summer.

15. The "anvil" effect produced on a frozen roadbed in connection with the defects and conditions before noted appears to be the cause of rail failures in winter rather than any change in the steel which may be produced by cold.

16. Recent rail breakage as compared with the past is to a great extent due:

(*a*) To the gradual exhaustion of pure ores suitable for the Bessemer process, which has made it necessary to permit the increase of the proportion of phosphorus in the finished rail from 0.06 per cent to 0.10 per cent, or over 60 per cent;

(*b*) To the rapid increase of wheel weights and speeds brought about by traffic requirements, which has resulted in more severe conditions of service than have ever before been imposed in railroad history.

17. The following are among the methods which will probably be found to be most effective in reducing rail breakage:

(*a*) Improved maintenance of equipment, especially of wheels, and reduction in the number of worn and flat wheels; improved balancing of locomotives; improved track design and maintenance, including effective drainage, ample depth of ballast, and uniform tie spacing.

(*b*) The substitution of open-hearth for Bessemer steel, with consequent reduction of phosphorus.

(*c*) Improved methods of manufacture, especially directed to secure sound ingots, sufficient discard to remove the segregated and defective metal at the top of the ingot.

(*d*) Heavier rails and improved sections, and especially sections with heavier bases.

(*e*) Rigid specifications and careful inspection of all details of manufacture.

18. The electric track circuit in connection with the signal system appears to be the most effective method of detecting broken rails and preventing accidents therefrom.

19. Much progress has been made by the principal lines in solving the rail-failure problem. The Harriman lines report: **Mr. Webster.**

"To sum the matter up, our rails are over eight times better since January, 1910, than they were for three years before that date.

"The causes of our success are, we think, due to improvements in:

"(*a*) Mill practice: Increased care and vigilance by the manufacturers;

"(*b*) Rail section: Thicker base and better-balanced section;

"(*c*) Chemical constituents: Less segregation and better selection of carbon constituent;

"(*d*) Inspection: More thorough and including all steps of the process, day and night, at much increased cost to us;

"(*e*) Selection of maker: Placing our orders with those mills which have given us the best product."

20. The final conclusions of the committee are:

(*a*) That present conditions do not require the inspection by the government of rails and equipment, or legislation concerning specifications or inspection.

(*b*) The most effective governmental method of securing continued improvement in the rail situation is the careful and thorough investigation of all important accidents which may be caused by rail breakage. In this connection it is desirable that each state commission should keep informed as thoroughly as may be practicable regarding the rail failures upon the lines under its supervision.

(*c*) The government tests of rails and ingots which were begun a few years ago should be continued and special study should be given to rail steel made by the basic open-hearth process.

"*Duty of the Federal and State Authorities in Connection with Rail Failures.*—This inquiry has been made primarily with a view to giving a satisfactory answer to the question indicated by the president of the Association and stated at the beginning of this report, as follows:

'Whether the matter of government inspecton may not be desirable, both in the matter of manufacturing rails and the construction of equipment, and perhaps legislation enacted requiring a rigid inspection and more uniformity in the specifications used by the different factories.'

"Our answer is that present conditions do not require the inspection by the government of rails and equipment or legislation concerning specifications or inspection.

"Finally, your committee would recommend the continuance of the government test of rails and ingots which were begun a few years ago and which are referred to in the body of this report. These tests were planned by a committee composed of government officers and of high grade experts from civil life representing both railroads and manufacturers. The tests were partially completed under the supervision of Mr. J. E. Howard, and the

Mr. Webster. results embodied in a congressional report are recognized as of great value. The work was, however, stopped by the government before definite conclusions could be reached. We believe that it should be continued along the same general lines as originally planned, and that special study should be given to rail steel made by the basic open-hearth process."

Mr. Shore. MR. ALBERT F. SHORE (*by letter*).—In my estimation the metallurgists have been performing their part admirably well, but it is undoubtedly a fact that since the problem of increasing the endurance of rails is a multiphase one, it is not within the province of metallurgy, after all commercial contingencies have been considered, to completely solve this problem.

Much of the longevity of a rail depends upon the correct relation of non-spring supported wheel mass to rail mass, and upon the uniformity of the supporting power of cross-ties, especially under high velocities. Thus if a greater part of the entire weight of the train, including the immense solid and rigid masses composing some of the wheels, could be placed above springs or their equivalent, a new era in railroad economy and safety might be looked for.

According to the laws of impact of solid bodies, the spring-supported tonnage, and the speed of the train, on a well-built track are less destructive to the rails than the wheel masses, which act as true colliding bodies. This action is due either to uneven supporting power of the ties under well-balanced wheels having excessive rigidity and mass, or to uniformly supported rail under poorly-balanced wheels. A perfectly uniformly supported rail is not commercially possible. Hence, we must make such amendments in methods of general mechanical construction as are possible.

I believe the greatest imperfection is in the rolling stock; consequently it is from this angle that we must attack the problem. We must reduce to a minimum the rigid masses in the wheels wherever permissible, and where this cannot be done, as with the locomotive-wheel counterweights, these masses—well nicknamed "Rail Crushers"—must be made ineffective in their relation to the rails, but yet remain effective in their counterbalancing relation to the reciprocating parts.

The more extensive use of higher grade material now already being called for will permit a generally lighter and more elastic

construction of all wheels. The locomotive-wheel counterweight will exert the selective effect called for by dividing it in sections, as a block between each two spokes riveted together from each side and with strips of wood between these and the outer rim. This would be equivalent to a spring support in its relation to rails, but not necessarily in relation to the reciprocating parts. The divided or sectional counterweight is based on the principle that a pound of pebbles in a bag hurled at a man is not so destructive as the same weight in a solid rock. The rigidity of the wheel can be otherwise reduced, consistent with strength, and the shock can be absorbed within the wheel itself instead of communicating it to the rails by the use of slightly tangent spokes. These would set up lateral vibration, and when this occurs, a linear shock cannot be transmitted as now. Mr. Shore.

RESULTS OF TESTS OF WELDED BOILER TUBES.

By E. L. Lasier.

The Bureau of Standards has made a series of tests upon welded boiler tubes for the Division of Locomotive Boiler Inspection of the Interstate Commerce Commission. It is with the permission of the Chief Inspector of Locomotive Boilers that the results of tests contained in this paper are given.

When one considers that during the last fiscal year 63 accidents, resulting in 1 death and 70 injuries, have resulted from the failure of locomotive boiler tubes, the importance of a better knowledge of the strength of welded tubes is apparent. It is because of this fact and of the meagreness of published data upon this subject that the following results of tests are offered.

A tension test is a test from practical conditions in locomotives boilers, where the weld is subjected to a direct tensile stress.

Tests were made upon several combinations of welded tubes as is shown in Table I (Plate XVI). Most of those reported are upon lap-welds; while some butt-welds are also included in the series. Specimens were selected having iron for the old end, iron for the safe end; iron for the old end, steel for the safe end; or steel for the old end, and steel for the new end. Also several of the specimens were of what is known as spellerized steel for either the new safe end or for both ends.

To make these tests, special cylindrical plugs were turned down until they exactly fitted the inside of each of the ends of the tubes. Special grips were also made with round concave gripping surfaces so as to firmly hold the specimen and enclose the ends of it until only approximately $\frac{1}{8}$ in. of the metal was visible in the grips. In this way a firm bearing pressure was brought to bear in holding the tube specimens. The tests were all made in a 200,000-lb. Olsen machine, lengths of specimens varying slightly and usually being from 12 to 15 in.

In order to appreciate better any inferences to be drawn from a study of Table I, and in order especially to interpret

TABLE I.—RESULTS OF TESTS OF WELDE

Mark.	Description.	Nominal Diameter, in.	Sectional Area, sq. in.	Loads in Pounds at Elongation in 3-in. of			E F inc
				0.01 in.	0.02 in.	0.03 in.	
A1	Old end, iron; new end, globe steel	1½	0.646	2 000	11 550	19 700	
2	" " " " " " "	1½	0.646	2 250	11 450	20 200	
B1	Old end, spellerized steel; new end, spellerized steel	1½	0.698	2 430	11 600	21 800	
2	" " " " " " " "	1½	0.622	2 200	11 650	21 600	
C1	Old end, cold-drawn steel; new end, spellerized steel	2	0.887	2 000	11 700	19 700	
2	" " " " " " " " "	2	0.877	1 500	11 800	19 450	
3	" " " " " " " " "	2	0.815	2 300	9 000	19 050	
D1	Old end, iron; new end, globe steel	1½	0.661	2 200	11 300	19 850	
2	" " " " " iron	1½	0.717	2 550	11 075	19 460	
E1	Old end, iron; new end, globe steel	1½	0.588	2 000	9 650	17 010	
2	" " " " " " "	1½	0.694	3 400	12 450	21 675	
F1	Old end, iron; new end, spellerized steel	1½	0.708	1 750	11 400	19 650	
2	" " steel " " " "	1½	0.717	1 600	12 710	21 000	
3	" " spellerized steel; new end, spellerized steel	1½	0.772	3 050	10 900	21 040	
G1		1½	0.653	2 000	12 500	21 600	
2		1½	0.661	1 600	11 600	20 400	
3		1½	0.708	3 100	11 100	20 500	
H1		1½	0.818	2 150	10 650	21 000	
2		1½	0.818	1 880	10 100	19 560	
I1		1½	0.756	2 800	10 850	19 250	
2		1½	0.915	1 650	10 150	20 700	
3		1½	0.854	1 800	10 000	19 330	
4		1½	0.765	1 600	10 700	19 050	
J1		2½	1.38	4 700	15 000	37 000	
K1	Butt-joint weld	2	0.792	1 800	10 500	20 250	
2	" " "	2	0.800	2 150	11 300	21 240	
3	" " "	2	0.737	2 350	10 850	22 320	
4	" " "	2	0.807	1 780	10 600	20 850	
5	" " "	2	0.744	2 000	10 500	20 540	
6	" " "	2	0.800	2 200	10 700	20 250	
L1	New end, charcoal iron	1½	0.784	4 100	15 950	18 500	
2	" " " "	1½	0.784	8 210	16 950	19 410	
M1	Old end, iron; new end, steel	1½	0.791	2 000	8 900	25 900	
2	" " " " " "	1½	0.722	6 270	25 400	30 140	
N1	Old end, iron; new end, steel	1½	0.772	17 350	24 050	25 350	
2	" " " " " "	1½	0.702	8 300	.....	.....	
O1	Old end, iron; new end, steel	1¼	0.477	11 300	16 400	19 100	
2	" " " " " "	1¼	0.561	9 600	16 250	17 000	

ESULTS OF TESTS OF WELDED BOILER TUBES.

ds in Pounds at Elongation in 3-in. of		Elongation after Fracture in 3-in. Gage Length, including Fracture, per cent.	Ultimate Strength.		
0.02 in.	0.03 in.		Total Load, lb.	Unit Stress, lb. per sq. in.	
11 550	19 700	13.3	23 000	35 600	Iro
11 450	20 200	12.7	26 580	41 100	Iro
11 600	21 800	14.0	33 490	48 000	Me
11 650	21 600	14.3	33 310	53 500	Me
11 700	19 700	14.7	38 120	43 000	En
11 800	19 450	6.7	35 900	40 900	Ins
9 000	19 050	5.0	37 650	46 200	En
11 300	19 850	18.7	32 910	49 800	On
11 075	19 460	11.3	30 580	42 600	Me
9 650	17 010	10.3	30 080	51 200	Me
12 450	21 675	6.0	35 010	50 500	Me
11 400	19 650	22.3	29 850	42 200	Iro
12 710	21 000	10.7	31 620	44 200	On
10 900	21 040	8.7	30 500	39 500	
12 500	21 600	6.3	25 100	38 500	Me
11 600	20 400	11.3	28 450	43 100	Me
11 100	20 500	29.3	34 560	49 000	Me
10 650	21 000	15.3	36 940	45 200	Me
10 100	19 560	5.0	19 570	23 900	On
10 850	19 250	19.7	30 420	40 300	Me
10 150	20 700	5.7	28 430	31 100	En
10 000	19 330	16.7	28 570	33 420	Me
10 700	19 050	19.0	28 160	36 750	
15 000	37 000	33.0	65 200	47 200	Me
10 500	20 250	3.3	24 250	30 600	We
11 300	21 240	3.7	37 100	46 400	"
10 850	22 320	7.7	35 200	47 800	"
10 600	20 850	4.7	35 450	43 900	"
10 500	20 540	2.7	27 000	36 300	"
10 700	20 250	1.7	25 420	31 800	"
15 950	18 500	9.0	27 300	34 800	Me
16 950	19 410	8.3	30 630	39 200	
8 900	25 900	...	32 770	41 400	Ex
25 400	30 140	...	39 810	55 200	Ir
24 050	25 350	...	34 870	44 850	"
.....	.....	...	12 090	17 200	Ex
16 400	19 100	...	27 720	58 200	Ir
16 250	17 000	...	24 100	42 950	"

·.	Location of Fracture.
trens, sq. in.	
00	Iron metal failed, 1 in. from weld.
00	Iron metal at one end of weld failed, steel remaining intact.
00	Metal failed at weld.
00	Metal failed, 1 in. from weld.
00	Entire weld separated.
00	Inside metal failed at weld.
00	Entire weld separated, also part of inside metal torn.
00	One-half of iron metal failed at weld; one-half of weld separated.
00	Metal failed at weld.
00	Metal failed 1 in. from weld.
00	Metal failed at weld.
00	Iron metal failed 1 in. from weld.
00	One-half of metal failed at weld; one-half of weld separated.
00	" " " " " " " " " "
00	Metal failed at weld.
00	Metal at one end of weld failed.
00	Metal failed 2 in. from weld.
00	Metal failed at weld.
00	One-half of metal failed at weld; one-half of weld separated.
00	Metal failed $1\frac{1}{2}$ in. from weld.
00	Entire weld separated.
20	Metal failed $1\frac{1}{2}$ in. from weld.
50	" " " " "
00	Metal failed near weld.
00	Weld separated.
00	" "
00	" "
00	" "
00	" "
00	" "
00	Metal failed at weld.
00	" " " "
00	Entire weld separated.
00	Iron metal failed at weld.
50	" " " " "
00	Entire weld separated.
00	Iron metal failed at weld.
50	" " " " "

more intelligently the causes of failures in the light of heat treatment in forming the weld, or of injuries inflicted upon the metal at or a short distance from the weld due to mechanical treatment, a very brief review of the customary practice followed in welding tubes will be given.

According to very usual practice, it is customary to safe-end and replace in service all tubes found defective, if the inspec-



A1. A2.

FIG. 1.—Old End, Iron; New End, Globe Steel.

tion proves that they can again be used. Defects in withdrawn tubes usually occur near the point where the tube enters the flue sheet, such defects being cut off and then having a safe end added. The end of the tube cut off is heated to the proper color temperature, and then expanded upon a tapered mandrel, so as to form a pocket into which the safe end is placed for a lap weld. Both parts are now heated together until a welding



C1. C2. C3.

FIG. 2.—Old End, Cold-Drawn Steel; New End, Spellerized Steel.



D1 D2.

FIG. 3.—Old End Iron; New End, Globe Steel (D1), Iron (D2).

temperature or about 2200° F. is reached, when they are revolved and pressure applied at the section to be welded until the weld is sound. The safe end is now heated to a bright red heat, or the operation is combined with that of welding, so as to swedge the safe end to proper size. The temperature usually



K4. K5. K6.

FIG. 4.—Butt-Joint Weld.

attained in the operation of welding reaches as high as 2700° F. and it is apparently not uncommon because of the high heat and lack of sufficient working, to break down the structure and to produce a more or less injurious effect upon the metal.

A process that has gained considerable vogue is a process known as spellerizing. Spellerizing is a method of subjecting

the skelp to rolls surfaced with regular projections, and then subjecting the hot bloom to rolls with smooth surfaces. This operation is repeated, it being claimed that the surface of the metal is better worked and a uniformly dense texture produced, the working required varying according to the thickness of the walls.

Figs. 1 to 4, inclusive, show photographs of ten welded boiler tubes which have been tested in tension and are reported in Table I (Plate XVI), and are illustrations of all of the failures possible.

In Fig. 1 are shown two classes of failure. Both of the tubes consisted of an iron old end, and a steel safe end. Specimen A1 broke in the iron old end 1 in. from the weld, under

TABLE II.—SUMMARY OF TABLE I.

Character of Failure.	Specimen Mark.	Number of Tubes.
Metal failed outside of weld	A1—B2—E1—F1—G3—L1—I3 I4—J1	9
Metal failed at weld	A2—B1—C2—D2—E2—G1—G2 H1—L1—L2—M2—N1—O1—O2	14
Entire weld separated	C1—C3—I2—K1—K2—K3—K4 K5—K6—M1—N2	11
Part of weld failed; part of metal failed at weld	D1—F2—F3—H2	4

a load of 35,600 lb. per sq. in. Specimen A2 is typical of the most common of the failures, the metal (the old iron metal) breaking at the weld—in this case at the extremity of the welded portion. It is to be noted that the breaking load required for A2 was over 5000 lb. per sq. in. more than was required for A1.

Specimens C1, C2, and C3, shown in Fig. 2, are all tubes with steel for the old end, and spellerized steel for the safe end. C1 and C3 are examples of the entire weld separating; C2 again shows a tube in which the metal at the weld failed first. Attention is called to the fact that C2 failed at a lower unit stress than either C1 or C3.

In Fig. 3, specimens D1 and D2 are shown. D1 has iron for the old end, with steel for the safe end; D2 consists of an

iron tube for both ends. In D1, one-half of the metal failed at the weld, and one-half of the weld itself failed. In D2 there is shown another example of the metal failing at the weld. Again, where part of the weld failed, a higher unit load was required than where the metal alone failed.

Three tubes with butt-welds are shown in Fig. 4, K4, K5 and K6. In each case the weld separated.

From a study of Table I, giving tests of the 38 specimens selected, Table II has been drawn up, giving the results in a summarized form.

The tests herein reported are far from complete nor are they satisfactorily definite. They may, however, be considered as contributory to our knowledge of the strength of welded boiler tubes.

NOTES ON THE PROPERTY OF TOUGHNESS OF METALS.

By Albert F. Shore.

A metal to be tough must have a high elastic strength and considerable ductility. A brittle metal of great strength is not tough, nor is a ductile metal of low strength. It is difficult sometimes to tell just when toughness begins; for example, the plasticity of such a metal as lead is a different property from the ductility of gold.

The property of toughness in metals does not appear to have been directly measured up to the present time. In that connection it is desirable that a scale for the measurement of toughness should be provided, such as we have for indicating temperature, pressure, or hardness.

Methods of Determining Toughness.

There are three methods of determining the factors of strength and ductility constituting toughness, as follows:

1. By making a tension test, which gives the elastic limit in pounds per square inch and the percentage of elongation in any desired length;

2. By making a cold-bend test, from which may be determined the elastic limit in pounds per square inch and the number of degrees of permanent bend;

3. By making two tests: the hardness test, which gives the hardness numeral, and the cold-bend test, which gives the number of degrees of permanent bend.

In each of these three methods two properties are determined, which when expressed as one versus the other (for example, by the first method, 45,000 lb. per sq. in. *vs.* 25 per cent) convey a definite idea and an accurate estimate of the toughness of the metal.

ADVANTAGES AND DISADVANTAGES OF EACH METHOD.

The first method is probably the one most preferred because it is in most general use at the present time, and is therefore best understood. From the standpoint of economy it has the disadvantage that a rather complex test specimen must often be made; while if an unprepared specimen is used, a comparatively large size is required on account of the wedge grip used.

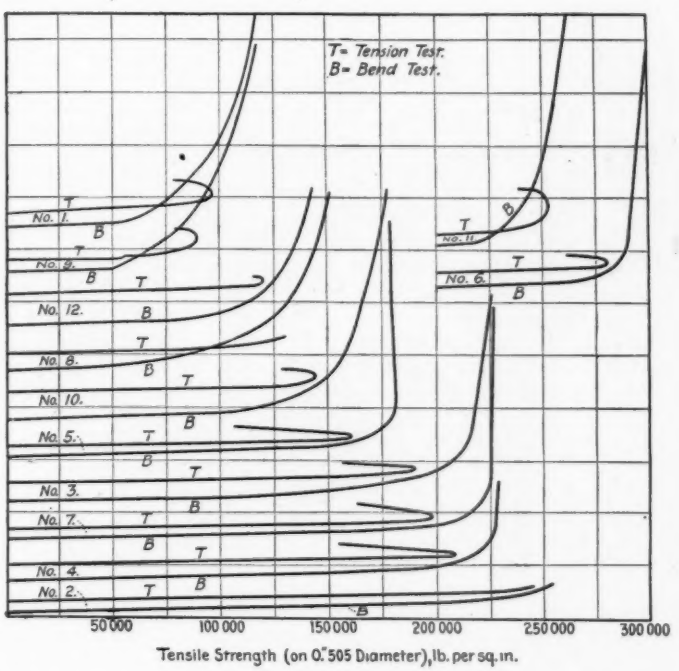


FIG. 1.—Curves showing Relation between Tension and Bend Tests.

Scientifically, the elongation obtained on a tension test specimen is indefinite. In annealed brass and copper the whole piece will elongate, while in the case of the harder metals most of the elongation is confined to the spot where the break occurs; so in speaking of elastic limit versus percentage of elongation a somewhat vague idea of the toughness is given.

The bend test specimen does not have to be especially

prepared. The elastic limit, ultimate strength and the number of degrees of permanent bend can be very clearly defined on the autographic chart, taken from a bend test. Further, the elongation on the tension side of the neutral axis is confined to a definite and known place, so that in speaking of degrees of permanent bend, we have a more accurate estimate of ductility than can be obtained from the elongation of the tension test specimen.

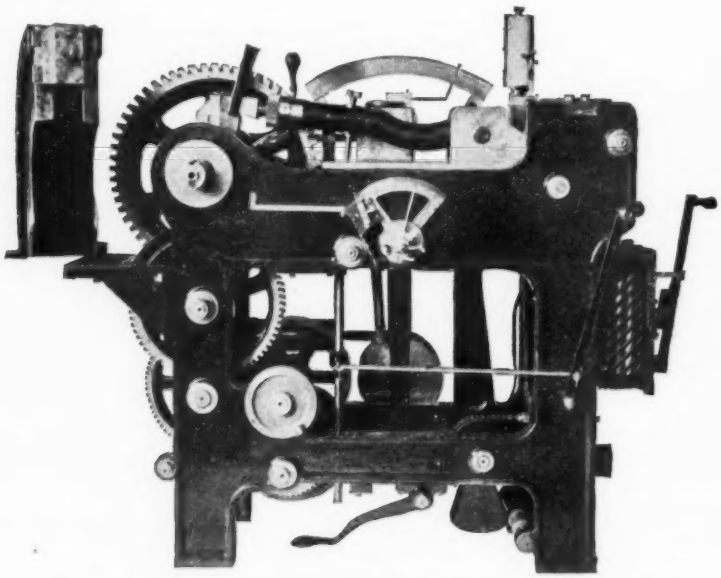


FIG. 2.—The Shore Compensating Universal Testing Machine, Front View. Equipped for Bend Tests.

The third method is necessarily so approximate that it is not satisfactory for regular use in the laboratory; but as a "sub" or "deputy" test, it is so simple that it is by far the most generally used for inspection purposes in one modified form or other. This can be illustrated by the following example in actual practice: A number of gears are made and heat-treated in the same way as the master test specimen, the strength, hardness and ductility of which have been determined in the usual manner. Since in this case the heat treatment is for

hardening, it will be necessary to test the gears for hardness only, to see that the hardness value agrees with that of the master specimen. This in turn assures the same toughness value in the gears as in the specimen.

In many instances a hardness test on soft steel, in connection with the ductility factor, has solved the problem of individual piece inspection; and the method is being adopted by the railroads for testing car axles, etc.

It is also possible to test in this way the toughness of very large forgings or castings in a number of places, by sawing off a sliver, bending it in a vise, and then measuring its hardness.

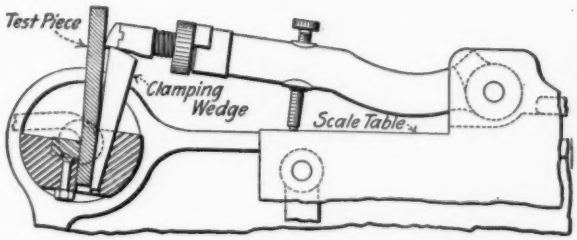


FIG. 3.—Diagram showing how the Cantilever Bend Tests are made.

RELATION OF BEND AND TENSION TEST READINGS.

The desirability of being able to resolve the readings of the tension test into those of the bend test, or *vice versa*, is evident to all.

It is a well-known fact that a metal which shows a high tensile strength will show high values on almost any kind of strength test applied to the same piece, whether it be the bend, torsion, compression, shear or hardness test.

According to experiments made by the writer, there is a definite relation between the results of the tension and bend tests. This is shown graphically in Fig. 1, on which are plotted stress-strain curves for tension (marked T) and autographic curves for the bend tests (marked B). The scale figures at the bottom of the diagram apply directly to the curves for tension only.

The following list describes the steels and the heat treatment to which they were subjected; the numbers correspond to those on the curves in Fig. 1:

No. 1.....Nickel steel, annealed.
No. 2.....Vanadium tool steel, hardened at 1500° F. in water, drawn 800° F.
No. 3.....Chrome-nickel steel, hardened at 1500° F. in oil, left so.
No. 4.....Nickel steel, hardened at 1500° F. in water, drawn 750° F.
No. 5.....Chrome-nickel steel, hardened at 1500° F. in water, drawn 800° F.
No. 6.....Machine steel, cold-rolled.
No. 7.....Nickel steel, hardened in oil at 1500° F., left so.
No. 8.....Vanadium tool steel, hardened at 1500° F. in air blast, left so.
No. 9.....Vanadium tool steel, annealed.
No. 10.....Chrome-nickel steel, annealed.
No. 11.....Machine steel, hot-rolled.
No. 12.....High-speed steel, annealed.

Both the tension and bend tests were made on a new automatic and autographic machine of high precision, a view of which is shown in Fig. 2.

The method of making the bend test is illustrated diagrammatically in Fig. 3. The ratio of supported length to thickness of specimen was six.

Since the power of the scale can be adjusted to any desired degree by use of a pendulum balance, and since the load on the free end of the bend test specimen is only a fraction (5 per cent) of what would be required to rupture a tension specimen of the same area, the scale of each bend test curve has been enlarged twenty times.

By this method the average relation between the ultimate strengths as indicated by tension and bend tests, the latter being made as aboved described, is constant within 5 per cent plus or minus. The elastic limits show wider variation, averaging 10 per cent plus or minus.

TESTS ON THE RATE OF CORROSION OF METALS.

By A. W. Carpenter

This paper gives the further results, to date, of the second and third series of corrosion tests described in the author's paper published in the Proceedings of the Society for 1911,[1] and entitled "Some Tests of the Rate of Corrosion of Metals Exposed to Locomotive Gases"; together with data for and results of some additional tests.

Two additional 60-day exposures of the Second Series, Weehawken Tunnel Tests, were made, and the data and results for the complete series are shown in Table I (Plate XVII). The table duplicates that in the 1911 paper for the test data and the results of the examinations after the first and second exposures of 231 and 58 days, respectively, with slight corrections of the calculated figures for losses in weight per unit of surface, and the omission of the total losses in weight, which were rather immaterial. The unit losses for each exposure and for the successive totals of the four exposures are given. Finally, a column has been added giving the calculated average loss in thickness of each exposed surface per annum, assuming a uniform rate based on the total loss at the last examination, which was after four exposures for a total of 409 days. This column shows that the "special-iron" plain plate had an average rate of corrosion about double those of the other plates, which comprised a galvanized plate of the same "special-iron," a "special-coated" ferrous-metal plate, and a soft-steel plate. It should be noted that in the exposure after the first one, which was a long one of 231 days, the rate of corrosion of the "special-iron" plain plate was not so greatly in excess of the others, and in the case of the second exposure was as low as any. It will be seen that after the first exposure the coated plates corroded as fast, in general, as the plain plates; and in fact, the rates of corrosion of

[1] Vol. XI, p. 622.

all plates were remarkably near to equal for the total of the last three exposures.

The differences in rates of corrosion between the earlier and the later exposures may be largely explained the same as hereinafter in connection with the Third Series tunnel test. The composition of the coating of the "special-coated" metal was not determined; later, additional sheets of what was represented as the same material were obtained and analysis showed the coating to be composed of zinc and tin (see analysis of plate 054 in Table IV). The tunnel tests of this series were discontinued after the fourth exposure. The smoke-jack tests of the same series were discontinued after the third exposure (193 days total) and were fully reported in the 1911 paper.

An examination of the surfaces of the tunnel test plates after the last exposure showed them to be quite smooth, except in case of the "special-iron" plain plate, which was distinctly pitted.

The data for and the results of the first exposure in the Third Series, Weehawken Tunnel Tests, were given in the 1911 paper. Four additional exposures and examinations have been made, the data and results of which are given in Table II (Plate XVII), together with those given in the 1911 paper, revised, and a column showing the calculated average rate of corrosion per annum, as explained for the corresponding case in Table I. The second and third exposures were of 60 days duration each, and the fourth and fifth were of 120 days each, giving a total exposure of 418 days.

Some surprising differences in the rate of corrosion of the same plates for the different exposures will be noted. This may, in a large measure, be explained by the fact that a mechanical blower was installed at the westerly end of the tunnel after the second exposure of the test plates. This blower operates to blow fresh air into the tunnel and force the gases out at the easterly end. There are two fans both of which are operated in winter and cold weather, but only one in summer and warm weather. Under favorable conditions the tunnel is entirely cleared of gases after the passage of a train, but when easterly winds prevail the clearing is not so effective. The result is to produce a variable condition in the atmosphere of the tunnel,

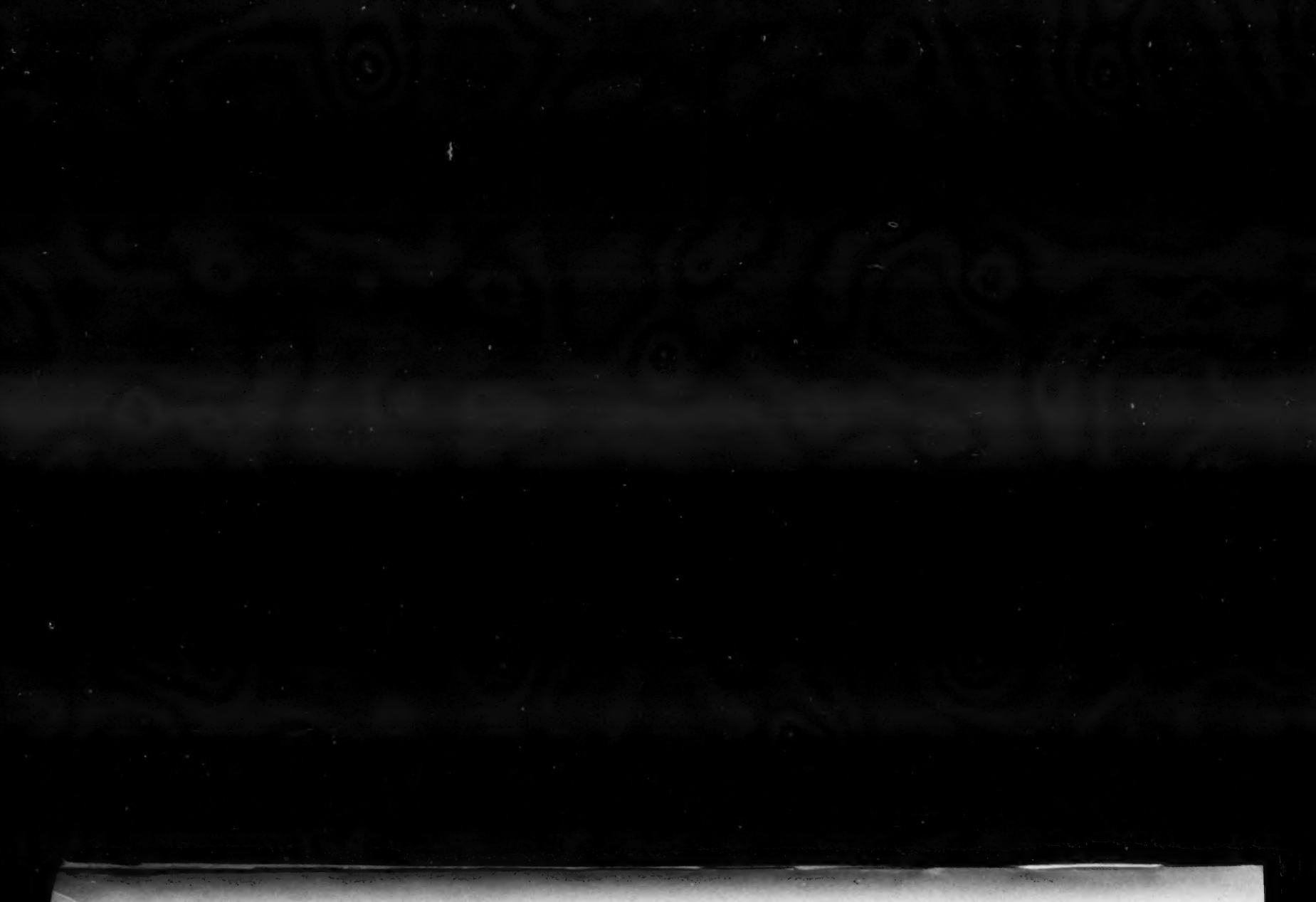


TABLE I.—FIRST SE

EXPOSED IN WEEHAWKEN

Plate No.	Kind of Metal.	Dimensions,[1] in.	Area of Surface, sq. in.	Weight before Exposure, grams.	Chemical Analysis, per ce (See footnote for copper.)			
					Si	S	P	Mn
1	Special coated metal[2]	$10\frac{1}{4} \times 12 \times \frac{1}{32}$	246.4	458	0.02	0.056	0.116	1.02
		$9\frac{3}{8} \times 12 \times \frac{1}{32}$	227.0	317	0.05	0.105	0.122	0.37
3	Soft, open-hearth steel, box annealed, plain	$10\frac{1}{4} \times 12 \times \frac{1}{16}$	249.0	1006	0.05	0.026	0.019	0.39
		$9\frac{1}{4} \times 12 \times \frac{1}{16}$	225.0	783	0.04	0.035	0.013	0.37
4	Special iron "A," plain	$11 \times 12 \times \frac{1}{16}$	267.0	1084	0.02	0.021	0.015	Non
		$10 \times 12 \times \frac{1}{16}$	243.0	585	0.01	0.029	0.006	Non
6	Special iron "A," galvanized	$10\frac{7}{8} \times 12 \times \frac{1}{16}$	263.3	1074	0.01	0.027	0.001	Non
		$9\frac{3}{4} \times 12 \times \frac{1}{16}$	237.0	825	0.06	0.026	0.006	Non

NOTE—The specimens were analyzed for copper, with the resulting report that none was found.
[1] After first examination, plates 1, 3, 4 and 6 had a 1-in. strip cut from the bottom for check analysis. The lower figures for di
[2] The upper rows of figures for plates 1, 4 and 6 are from analyses of mixed drillings from plates 1 and 2, 4 and 5, 6 and 7 respecti plates 1, 3, 4 and 6 are from check analyses on these plates individually. The upper row of figures for plate 3 applies to the origin
[3] Analysis of coating not made.
[4] Rate excepting first exposure, 0.011 in. per annum.

TABLE II.—THIRD

EXPOSED IN WEEHAWKE

Plate No.	Kind of Metal.	Dimensions, in.	Area of Surface, sq. in.	Weight before Exposure, grams.	Chemical Analysis, per cent. (See footnote for copper.)					
					Si	S	P	Mn	C	Pb
01	Special iron "B," plain	$11 \times 12 \times \frac{1}{16}$	267	979	0.03	0.029	0.006	0.03	Trace	....
03	Special iron "B," plain	$11 \times 12 \times \frac{1}{16}$	267	959	0.02	0.034	0.005	0.03	Trace	....
019	Special iron "B," galvanized	$11\frac{1}{8} \times 12 \times \frac{1}{16}$	269.8	1037	0.01	0.041	0.006	0.03	Trace	None
05	Wrought iron, plain (rolled from piled puddle iron)	$11 \times 12 \times \frac{1}{8}$	270	2200	0.05	0.039	0.170	0.01	0.06	....
015	Wrought iron, plain (rolled from piled puddle iron)	$4 \times 11 \times \frac{1}{8}$	91.8	725	0.07	0.041	0.160	0.01	0.06	....
07	Soft open-hearth steel, plain	$11\frac{1}{16} \times 12 \times \frac{1}{8}$	271.3	2204	0.02	0.039	0.017	0.41	0.19	....
017	Soft open-hearth steel, plain	$4 \times 11 \times \frac{1}{8}$	91.8	722	0.02	0.039	0.020	0.44	0.18	....
09	Special non-ferrous metal, plain	$11 \times 12 \times \frac{1}{16}$	267	1197	Assumed same as Plate 010[4]					
011	Lead coated, galvanized steel	$10\frac{7}{8} \times 12 \times \frac{1}{16}$	263.9	849	0.01	0.080	0.086	0.39	0.08	1.90
013	Lead coated galvanized steel	$11\frac{1}{16} \times 12 \times \frac{1}{16}$	268.4	920	0.01	0.059	0.083	0.34	0.08	4.03
037	Special iron "A," plain	$10\frac{7}{8} \times 12 \times \frac{1}{16}$	263.9	953	0.01	0.035	0.003	None	Trace	....
039	Special iron "A," plain	$11 \times 12 \times \frac{1}{16}$	267	957	0.01	0.035	0.003	None	Trace	....
041	Special iron "A," galvanized	$10\frac{7}{8} \times 12 \times \frac{1}{16}$	263.9	1009	0.01	0.026	0.001	None	Trace	None
021	Bessemer steel bar	$3 \times 12\frac{1}{2} \times \frac{5}{8}$	83	1461	0.01	0.064	0.120	0.37	0.08	....

					Si	S	P	Mn

-FIRST SERIES.

EEHAWKEN TUNNEL.

alysis, per cent.[a] e for copper.)			Average Loss per Square Inch of Surface, grams.							Average Loss per Annum in Thickness, each Surface, in.	Plate No.
			First Examination.	Second Examination.		Third Examination.		Fourth Examination.			
P	Mn	C	First Exposure, 231 days.	Second Exposure, 58 days.	First and Second Exposures, 289 days.	Third Exposure, 60 days.	First to Third Exposures, 349 days.	Fourth Exposure, 60 days.	First to Fourth Exposures, 409 days.		
.116	1.02	0.09	0.43	0.11	0.54	0.16	0.70	0.36	1.06	0.007	1
.122	0.37	0.09									
.019	0.39	0.11	0.51	0.07	0.58	0.19	0.77	0.38	1.15	0.008	3
.013	0.37	0.10									
.015	None	Trace	1.66	0.07	1.73	0.22	1.95	0.41	2.36	0.016[a]	4
.006	None	Trace									
.001	None	Trace	0.61	0.08	0.69	0.14	0.83	0.43	1.26	0.009	6
.006	None	Trace									

igures for dimensions, areas and weights apply to the reduced plates.
nd 7 respectively. (Plates 2, 5 and 7 were exposed in the smoke-jack test; see 1911 paper.) The lower rows of figures for to the original analysis, the lower ones to the check analysis, both on this plate alone.

II.—THIRD SERIES.

WEEHAWKEN TUNNEL.

er cent. pper.)			Average Loss per Square Inch of Surface, grams.									Average Loss per Annum in Thickness, each Surface, in.	Plate No.
			First Examination.	Second Examination.		Third Examination.		Fourth Examination.		Fifth Examination.			
C	Pb	Zn	First Exposure, 58 days.	Second Exposure, 60 days.	First and Second Exposures, 118 days.	Third Exposure, 60 days.	First to Third Exposures, 178 days.	Fourth Exposure, 120 days.	First to Fourth Exposures, 298 days.	Fifth Exposure, 120 days.	First to Fifth Exposures, 418 days.		
race	....	....	0.08	0.13	0.20	0.45	0.65	0.13	0.78	1.05	1.83	0.012	01
race	....	....	0.09	0.06	0.14	0.43	0.57	0.13	0.70	1.15	1.85	0.013	03
race	None	3.79	0.14	0.11	0.25	0.05	0.30	0.13	0.43	0.89	1.32	0.009	019
.06	....	....	0.09	0.12	0.21	0.50	0.71	0.11	0.82	1.12	1.94	0.013	05
.06	....	....	0.09	Plate lost in tunnel.									015
.19	....	....	0.10	0.18	0.28	0.44	0.72	0.06	0.78	0.99	1.77	0.012	07
.18	....	....	0.09	0.17	0.26	0.46	0.72	0.10	0.82	1.08	1.90	0.013	017
te 010[d]			0.23	0.20	0.42	0.10	0.52	0.25	0.77	0.22	0.99	0.006[b]	09
.08	*1.90*	*1.58*	0.05	0.05	0.10	0.19	0.29	0.22	0.51	0.64	1.15	0.009[c]	011
.08	4.03	1.42	0.09	0.06	0.14	0.16	0.30	0.14	0.44	0.54	0.98	0.007[c]	013
race	....	....	0.05	0.15	0.20	0.48	0.68	0.13	0.81	1.03	1.84	0.013	037
race	....	....	0.05	0.09	0.13	0.51	0.64	0.12	0.76	0.68	1.44	0.010	039
race	None	*0.87*	0.12	0.09	0.21	0.11	0.32	0.12	0.44	0.98	1.42	0.010	041
			First Exposure, 42 days.	Second Exposure, 60 days.	First and Second Exposures, 102 days.	Third Exposure, 60 days.	First to Third Exposures, 162 days.	Fourth Exposure, 120 days.	First to Fourth Exposures, 282 days.	Fifth Exposure, 120 days.	First to Fifth Exposures, 402 days.		
.08	....	....	0.11	0.11	0.22	0.44	0.66	0.11	0.77	1.05	1.82	0.013	021

P	Mn	C	Exposure, 231 days.	Exposure, 58 days.	Exposures, 289 days.	Exposure, 60 days.	Exposures, 349 days.	Exposure, 60 days.	Exposures, 409 days.	in.	

					Si	S	P	Mn
1	Special coated metal[2]	$10\frac{1}{4} \times 12 \times \frac{1}{32}$	246.4	458	0.02	0.056	0.116	1.02
		$9\frac{3}{8} \times 12 \times \frac{1}{32}$	227.0	317	0.05	0.105	0.122	0.37
3	Soft, open-hearth steel, box annealed, plain	$10\frac{1}{4} \times 12 \times \frac{1}{16}$	249.0	1006	0.05	0.026	0.019	0.39
		$9\frac{1}{4} \times 12 \times \frac{1}{16}$	225.0	783	0.04	0.035	0.013	0.37
4	Special iron "A," plain	$11 \times 12 \times \frac{1}{16}$	267.0	1084	0.02	0.021	0.015	None
		$10 \times 12 \times \frac{1}{16}$	243.0	585	0.01	0.029	0.006	None
6	Special iron "A," galvanized	$10\frac{7}{8} \times 12 \times \frac{1}{16}$	263.3	1074	0.01	0.027	0.001	None
		$9\frac{3}{4} \times 12 \times \frac{1}{16}$	237.0	825	0.06	0.026	0.006	None

NOTE—The specimens were analyzed for copper, with the resulting report that none was found.
[1] After first examination, plates 1, 3, 4 and 6 had a 1-in. strip cut from the bottom for check analysis. The lower figures for dim
[2] The upper rows of figures for plates 1, 4 and 6 are from analyses of mixed drillings from plates 1 and 2, 4 and 5, 6 and 7 respectiv
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[3] Analysis of coating not made.
[4] Rate excepting first exposure, 0.011 in. per annum.

TABLE II.—THIRD
EXPOSED IN WEEHAWKEN

Plate No.	Kind of Metal.	Dimensions, in.	Area of Surface, sq. in.	Weight before Exposure, grams.	Chemical Analysis, per cent. (See footnote for copper.)					
					Si	S	P	Mn	C	Pb
01	Special iron "B," plain	$11 \times 12 \times \frac{1}{16}$	267	979	0.03	0.029	0.006	0.03	Trace	....
03	Special iron "B," plain	$11 \times 12 \times \frac{1}{16}$	267	959	0.02	0.034	0.005	0.03	Trace	....
019	Special iron "B," galvanized	$11\frac{1}{8} \times 12 \times \frac{1}{16}$	269.8	1037	0.01	0.041	0.006	0.03	Trace	None
05	Wrought iron, plain (rolled from piled puddle iron)	$11 \times 12 \times \frac{1}{8}$	270	2200	0.05	0.039	0.170	0.01	0.06	....
015	Wrought iron, plain (rolled from piled puddle iron)	$4 \times 11 \times \frac{1}{8}$	91.8	725	0.07	0.041	0.160	0.01	0.06	....
07	Soft open-hearth steel, plain	$11\frac{1}{16} \times 12 \times \frac{1}{8}$	271.3	2204	0.02	0.039	0.017	0.41	0.19	....
017	Soft open-hearth steel, plain	$4 \times 11 \times \frac{1}{8}$	91.8	722	0.02	0.039	0.020	0.44	0.18	....
09	Special non-ferrous metal, plain	$11 \times 12 \times \frac{1}{16}$	267	1197	Assumed same as Plate 010[d]					
011	Lead coated, galvanized steel	$10\frac{7}{8} \times 12 \times \frac{1}{16}$	263.9	849	0.01	0.080	0.086	0.39	0.08	*1.90*
013	Lead coated galvanized steel	$11\frac{1}{16} \times 12 \times \frac{1}{16}$	268.4	920	0.01	0.059	0.083	0.34	0.08	4.03
037	Special iron "A," plain	$10\frac{7}{8} \times 12 \times \frac{1}{16}$	263.9	953	0.01	0.035	0.003	None	Trace	....
039	Special iron "A," plain	$11 \times 12 \times \frac{1}{16}$	267	957	0.01	0.035	0.003	None	Trace	....
041	Special iron "A," galvanized	$10\frac{7}{8} \times 12 \times \frac{1}{16}$	263.9	1009	0.01	0.026	0.001	None	Trace	None
021	Bessemer steel bar	$3 \times 12\frac{1}{4} \times \frac{5}{16}$	83	1461	0.01	0.064	0.120	0.37	0.08	....
023	Bessemer steel bar	$3 \times 12 \times \frac{5}{16}$	81.4	1457	0.01	0.066	0.120	0.37	0.08	....
025	Bessemer steel angle	$2 \times 2 \times \frac{1}{4} \times 12$[a]	76	1158	0.01	0.105	0.100	0.45	0.08	....
027	Bessemer steel angle	$2 \times 2 \times \frac{1}{4} \times 12$[a]	76	1177	0.02	0.089	0.090	0.40	0.08	....
029	Open-hearth steel bar	$3 \times 11\frac{1}{2} \times \frac{5}{16}$	78.1	1369	0.02	0.052	0.007	0.27	0.09	....
031	Open-hearth steel bar	$3 \times 11\frac{7}{8} \times \frac{5}{16}$	80.6	1414	0.01	0.046	0.008	0.27	0.09	....
033	Open-hearth steel angle	$2 \times 2 \times \frac{1}{4} \times 12$[a]	76	1143	0.11	0.044	0.009	0.39	0.21	....
035	Open-hearth steel angle	$2 \times 2 \times \frac{1}{4} \times 12$[a]	76	1155	0.11	0.062	0.007	0.42	0.22	....

NOTE.—The ferrous specimens were analyzed for copper, with the resulting report that none was found. Analyses of plates 013 and 019 were made on
former and are indicated by italics.
[a] One leg of each angle for a length of 6 in. was cut off for analysis.
[b] Based on ratio of actual weight of special metal plates and calculated weight of a steel plate of same nominal dimension = 1.10 : 1.00. Otherwise
[c] Assumed plates homogeneous material of same unit weight as steel.
[d] Analysis of plate 010 (Series III exposed in smoke jack and lost). Si, 0.03; Fe, 2.37; Cu, 27.57; Ni, 69.68.

0.08	....	....	0.11	0.11	0.22	0.44	0.66	0.11	0.77	1.05	1.82	0.013	021

P	Mn	C	[illegible] Exposure, 231 days.	[illegible] Exposure, 58 days.	[illegible] Exposures, 289 days.	[illegible] Exposure, 60 days.	[illegible] Exposures, 349 days.	[illegible] Exposure, 60 days.	[illegible] Exposures, 409 days.	in.	
116	1.02	0.09	0.43	0.11	0.54	0.16	0.70	0.36	1.06	0.007	1
122	0.37	0.09									
019	0.39	0.11	0.51	0.07	0.58	0.19	0.77	0.38	1.15	0.008	3
013	0.37	0.10									
015	None	Trace	1.66	0.07	1.73	0.22	1.95	0.41	2.36	0.016[a]	4
006	None	Trace									
001	None	Trace	0.61	0.08	0.69	0.14	0.83	0.43	1.26	0.009	6
006	None	Trace									

gures for dimensions, areas and weights apply to the reduced plates.
d 7 respectively. (Plates 2, 5 and 7 were exposed in the smoke-jack test; see 1911 paper.) The lower rows of figures for
the original analysis, the lower ones to the check analysis, both on this plate alone.

.—Third Series.

Weehawken Tunnel.

r cent. per.)			Average Loss per Square Inch of Surface, grams.									Average Loss per Annum in Thickness, each Surface, in.	Plate No.
			First Examination.	Second Examination.		Third Examination.		Fourth Examination.		Fifth Examination.			
C	Pb	Zn	First Exposure, 58 days.	Second Exposure, 60 days.	First and Second Exposures, 118 days.	Third Exposure, 60 days.	First to Third Exposures, 178 days.	Fourth Exposure, 120 days.	First to Fourth Exposures, 298 days.	Fifth Exposure, 120 days.	First to Fifth Exposures, 418 days.		
race	....	....	0.08	0.13	0.20	0.45	0.65	0.13	0.78	1.05	1.83	0.012	01
race	....	....	0.09	0.06	0.14	0.43	0.57	0.13	0.70	1.15	1.85	0.013	03
race	None	3.79	0.14	0.11	0.25	0.05	0.30	0.13	0.43	0.89	1.32	0.009	019
.06	....	....	0.09	0.12	0.21	0.50	0.71	0.11	0.82	1.12	1.94	0.013	05
.06	....	....	0.09	Plate lost in tunnel.									015
.19	....	....	0.10	0.18	0.28	0.44	0.72	0.06	0.78	0.99	1.77	0.012	07
.18	....	....	0.09	0.17	0.26	0.46	0.72	0.10	0.82	1.08	1.90	0.013	017
e 010[d]			0.23	0.20	0.42	0.10	0.52	0.25	0.77	0.22	0.99	0.006[b]	09
.08	*1.90*	*1.58*	0.05	0.05	0.10	0.19	0.29	0.22	0.51	0.64	1.15	0.008[c]	011
.08	4.03	1.42	0.09	0.06	0.14	0.16	0.30	0.14	0.44	0.54	0.98	0.007[c]	013
race	....	....	0.05	0.15	0.20	0.48	0.68	0.13	0.81	1.03	1.84	0.013	037
race	....	....	0.05	0.09	0.13	0.51	0.64	0.12	0.76	0.68	1.44	0.010	039
race	None	*0.87*	0.12	0.09	0.21	0.11	0.32	0.12	0.44	0.98	1.42	0.010	041
			First Exposure, 42 days.	Second Exposure, 60 days.	First and Second Exposures, 102 days.	Third Exposure, 60 days.	First to Third Exposures, 162 days.	Fourth Exposure, 120 days.	First to Fourth Exposures, 282 days.	Fifth Exposure, 120 days.	First to Fifth Exposures, 402 days.		
.08	....	....	0.11	0.11	0.22	0.44	0.66	0.11	0.77	1.05	1.82	0.013	021
.08	....	....	0.19	0.12	0.30	0.42	0.72	0.11	0.83	1.11	1.94	0.014	023
.08	....	....	0.09	0.15	0.24	0.39	0.63	0.12	0.75	1.29	2.04	0.014	025
.08	....	....	0.11	0.15	0.26	0.44	0.70	0.17	0.87	1.19	2.06	0.015	027
.09	....	....	0.08	0.21	0.28	0.49	0.77	0.09	0.86	1.58	2.44	0.017	029
.09	....	....	0.09	0.11	0.20	0.57	0.77	0.12	0.89	1.45	2.34	0.017	031
.21	....	....	0.07	0.14	0.21	0.26	0.47	0.16	0.63	1.18	1.81	0.013	033
.22	....	....	0.05	0.15	0.21	0.25	0 46	0.15	0.61	1.15	1.76	0.012	035

ere made on sheared samples; of plates 011 and 041 on drilled samples. The lead and zinc contents of the latter are not considered as reliable as the

Otherwise all values in last column are based upon the assumed unit weight of steel = 128.3 grams per cu. in.

and to introduce a new element due to the strong current of air and gases. The plates were all grouped on a frame within an area of about twenty square feet near one side of the tunnel at about the middle of its length (which is about 4300 feet). In addition, the plates of same kind were separated in location on the frame and the position of each plate systematically changed in each succeeding exposure, so it would seem that the indiv dual plates have been subjected to practically equal conditions, and the results for each exposure show fair uniformity for the duplicate plates, and fair proportionality for those of different materials.

TABLE III.—THIRD SERIES, WEEHAWKEN TUNNEL TESTS.
418 DAYS EXPOSURE.

Relative Order of Resistance.	Kind of Metal.	Number of Specimens.	Calculated Rate of Corrosion per Annum in Thickness per Surface, in.
1.....	Special non-ferrous metal plate.....	1	0.006
2.....	Lead-coated, galvanized steel plates.....	2	0.0075
3.....	Special-iron "B," galvanized plate.....	1	0.009
4.....	Special-iron "A," galvanized plate.....	1	0.010
5.....	Special-iron "A," plain plates.....	2	0.0115
6.....	Soft, open-hearth steel, plain plates.....	2	0.0125
	Special-iron "B," plain plates.....	2	0.0125
	Open-hearth steel, plain angles.....	2	0.0125
7.....	Wrought iron, plain plate.....	1	0.013
8.....	Bessemer steel, plain bars.....	2	0.0135
9.....	Bessemer steel, plain angles.....	2	0.0145
10.....	Open-hearth steel, plain bars.....	2	0.017

NOTE.—Where there are two specimens, the average rate of corrosion for the two has been tabulated.

The results may be summarized by stating the metals in order of least loss from corrosion, together with the calculated average rate of loss per annum, as shown in Table III. Further exposures of the specimens are to be made.

It may be interesting to note that the nature of the corrosion on the specimens listed in Table III, as regards appearance of surface after exposure and cleaning, was very much alike in all cases, except that of the special, non-ferrous plate; in the latter case, as will be noted by reference to Table II, the greatest rate of loss occurred in the first two exposures, and was reduced about 50 per cent in the last three, during which it was remarkably uniform, and in that respect different from the others. It was

noted that the early corrosion of the non-ferrous plate was not a uniform reduction of the surface, but was in the form of deep and non-uniform pitting, as if the material were non-homogeneous in composition and as if the corrosion acted upon certain elements more vigorously than on others; this pitting did not seem to continue so markedly in the later exposures. The corrosion of the other specimens was not accompanied by marked pitting in any case although all surfaces were more or less rough. A small percentage of the surfaces of the lead-coated plates retained the coating after the fifth exposure.

The Third Series tests were planned to include exposures in engine-house smoke-jacks as well as those in the tunnel. A duplicate of the tunnel set was exposed in the Rensselaer engine-house stacks, and about one-half the specimens were lost by accident in the first exposure. Those lost were replaced with new plates of the same respective kinds, some new kinds added, and the tests continued at the High Bridge engine-house. Not more than two large specimens (11 by 12 in. approximately) or four small specimens (6 by 11 in. approximately) could be placed in any one jack, so it was impossible to insure equal conditions of exposure. The locations of the specimens were interchanged after each examination in the endeavor to obtain approximately equal conditions for the total average of exposures, but the results are still doubtful in this respect.

Five 60-day exposures and examinations have been made for the original specimens (those remaining after first exposure in which about one-half the specimens were lost), and four 60-day exposures for the specimens entered in the test after the first exposure. By discarding certain results which were manifestly abnormal and probably due to certain stalls in the engine-house not being in use during certain periods, a set of figures has been derived from the losses in weight, to represent the equivalent average rate of corrosion per annum. The presentation of the complete tabulation of this set of tests is not considered as warranted because the value of the results is made questionable by the defects in conditions of exposure, and because reference to Table II will answer for the description of most of the metals. In Table IV are given the analyses of the kinds of metals introduced into this test which were not included in the tests covered

by Table II; and also of the same kinds as shown in Table II which showed appreciable differences in analysis. Other than these, the results of analyses made on the specimens of the same kind for the two tests were practically identical. The approximate sizes of specimens for the smoke-jack tests were as follows: 11 by 12 by $\frac{1}{16}$ in. for special-iron "A," 6 by 11 by $\frac{1}{16}$ in. to $\frac{1}{8}$ in. for all others; except the Bessemer and open-hearth steel bars and angles, which were the same size as shown for corresponding

TABLE IV.—CHEMICAL ANALYSIS OF SPECIMENS OF THIRD SERIES, SMOKE-JACK TESTS, WHICH DIFFER MATERIALLY FROM THOSE OF CORRESPONDING KINDS GIVEN IN TABLE II, AND OF KINDS NOT INCLUDED IN TABLE II.

Plate No.	Kind of Metal.	Chemical Analysis, per cent.							
		Silicon.	Sulphur.	Phosphorus.	Manganese.	Carbon.	Lead	Zinc.	Tin.
040	Special-iron "A," galvanized (coating only)	.....	.....	.....	.....	.....	.....	4.35	.....
042	Lead-coated, galvanized steel	0.05	0.034	0.010	0.41	0.18	10.10	1.10	.....
044	Lead-coated, galvanized steel	0.05	0.035	0.013	0.42	0.18	4.65	2.40	.....
050	Wrought iron, plain	0.05	0.035	0.063	0.01	0.07	.....	.....	.....
062	Special-iron "B," galvanized	0.05	0.031	0.009	0 02	trace	.....	5.21	.....
054	"Special-coated" metal	0.02	0.043	0.063	0.38	0.17	trace	6.19	0.45
070	Special steel "A," plain[1]	0.04	0.048	0.024	0.30	0.07	.....	.....	.....
072	Special steel "A," plain[1]	0.02	0.049	0.032	0.31	0.07	.....	.....	.....

[1] Copper content claimed for this material by party who furnished it; our chemist reported no copper in any of the ferrous specimens, but later found 0.008 per cent copper in a supposed duplicate of plates 070 and 072.

NOTE.—After the presentation of this paper at the Annual Meeting of the Society, samples of plates 070 and 072 were sent to the manufacturer's chemist, who reported having analyzed them and finding about 0.2 per cent of copper —A. W. C.

specimens in Table II, and the "special-coated" metal specimens which were only about $\frac{1}{32}$ in. thick and disappeared during the fourth exposure. The latter in all probability were practically consumed by corrosion and fell as the result.

The list of the metals in the Third Series smoke-jack tests in relative order of resistance, determined as explained above, and the calculated rate of corrosion per annum for each is given in Table V.

The thought that possibly different comparative results

might be obtained under ordinary atmospheric conditions of exposure, led to the institution of a series of tests under such conditions. The data for the specimens exposed in this series, and the results for the two exposures of 120 days each, are shown in Table VI (Plate XVIII). It will be noted that this series includes a copper and an aluminum plate, and that practically no loss could be determined after the two exposures for either of these nor for the special non-ferrous metal, and only a trivial loss for any of the coated metals. The others are ranged in the following order of resistance shown in Table VII, with calculated rate of corrosion as given before for other tests.

TABLE V.—THIRD SERIES, SMOKE-JACK TESTS. 240 TO 300 DAYS EXPOSURE.

Relative Order of Resistance.	Kind of Metal.	Number of Specimens.	Calculated Rate of Corrosion per Annum in Thickness per Surface, in.
1.....	Lead-coated, galvanized steel plates.....	2	0.011
2.....	"Special-coated" metal plates.....	2	0.014
3.....	Special non-ferrous metal plates.....	2	0.015
	Special-iron "A," galvanized plate.....	1	0.015
4.....	Wrought iron, plain plates.....	2	0.017
5.....	Special-iron "B," galvanized plates.....	2	0.018
6.....	Special-steel "A," plain plates.....	2	0.019
	Special-iron "A," plain plates.....	2	0.019
7.....	Soft open-hearth steel, plain plates.....	2	0.021
8.....	Bessemer steel, plain bars.....	2	0.022
	Open-hearth steel, plain angles.....	2	0.022
9.....	Open-hearth steel, plain bars.....	2	0.023
10.....	Special-iron "B," plain plates.....	2	0.024
11.....	Bessemer steel, plain angles.....	2	0.025

NOTE.—Where there are two specimens, the average rate of corrosion for the two has been tabulated.

The excessive corrosion of one of the two steel plates "from Railroad Co. stock" (these plates were chosen purposely as representing different grades of material, although the analysis shows no appreciable difference except in manganese and carbon contents) will be at once noted. If this excessive rate continues in future exposures, the plate will be made a subject of special examination, in the endeavor to discover the cause for the same. It should be noted that all specimens in all series have been exposed in the condition they came from the manufacturers; that is, no preparation of surfaces was made in any case, and plain ferrous specimens always had the mill finish and mill scale on them. The plate with the excessive corrosion had lost all its

TABLE VI.—F

EXPOSED ON ROOF OF

Plate No.	Kind of Metal.	Dimensions, in.	Area of Surface, sq. in.	Weight before Exposure, grams.	
001	Special iron "B," plain	$5\frac{7}{8} \times 10\frac{7}{8} \times \frac{1}{16}$	129.9	509.5	N
002	Special iron "B," galvanized	$12 \times 12 \times \frac{1}{16}$	291.0	1068.0	N
003	Wrought iron plain (rolled from piled puddle iron)	$6 \times 12 \times \frac{1}{8}$	148.7	1009.0	N
004	Soft open-hearth steel, plain	$6 \times 11 \times \frac{1}{8}$	136.3	1060.0	N
005	Special non-ferrous metal, plain	$12 \times 12 \times \frac{1}{16}$	291.0	1232.0	N
006	Lead-coated galvanized steel	$6 \times 10\frac{3}{4} \times \frac{1}{16}$	131.1	549.5	N
007	Special iron "A," plain	$12 \times 12 \times \frac{1}{16}$	291.0	1098.5	N
008	Special iron "A," galvanized	$12 \times 12 \times \frac{1}{16}$	291.0	1145.5	N
009	Special steel "A," plain[1]	$12 \times 12 \times \frac{1}{16}$	291.0	1061.5	N
0010	Copper, plain	$4 \times 12 \times \frac{1}{16}$	98.0	452.5	C
0011	Aluminum, plain	$5\frac{5}{8} \times 8\frac{1}{2} \times \frac{1}{25}$	$\left\{\begin{matrix} 96.8 \\ 54.3^a \end{matrix}\right\}$	85.25	A
0012	Wrought iron, plain	$12 \times 12 \times \frac{1}{8}$	294.0	2167.0	N
0013	Steel from Railroad Co. stock "A," plain	$5\frac{1}{4} \times 10\frac{7}{8} \times \frac{1}{8}$	118.2	1016.0	0
0014	Steel from Railroad Co. stock "B," plain	$6 \times 11\frac{1}{16} \times \frac{1}{8}$	137.0	998.0	0
0016	Steel from Railroad Co. stock, galvanized	$5\frac{7}{8} \times 10\frac{15}{16} \times \frac{1}{16}$	130.6	410.0	0

[1] The special steel "A" was understood to have been manufactured with a percentage of copper purposely int
[a] A portion of this plate is protected by a coating of paint. The lower figure is the area of the portion not

TABLE VIII.—

EXPOSED IN WEEHAWKEN TUNNEL AND

Plate No.	Kind of Metal.	Dimensions, in.	Area of Surface, sq. in.	Weight before Exposure, grams.	
					TUNN
043	Special steel "A," plain	$6 \times 11 \times \frac{1}{16}$	134.1	479.0	N
045	Special steel "A," plain	$6 \times 10\frac{15}{16} \times \frac{1}{16}$	133.4	471.5	N
047	Aluminum, plain	$5\frac{5}{8} \times 6\frac{1}{16} \times \frac{1}{25}$	69.1	65.0	N
049	Copper, plain	$11 \times 12 \times \frac{1}{16}$	266.9	1267.0	C
051	Wrought iron, plain	$11 \times 12 \times \frac{1}{8}$	269.8	2014.0	.
053	Wrought iron, plain	$11 \times 12 \times \frac{1}{8}$	269.8	1957.5	.
					SMOKE-
074	Copper, plain	$5\frac{3}{4} \times 10\frac{15}{16} \times \frac{1}{16}$	127.9	602.0	C
076	Copper, plain	$6 \times 10\frac{7}{8} \times \frac{1}{16}$	132.6	629.5	P
078	Wrought iron, plain	$6\frac{1}{16} \times 12 \times \frac{1}{8}$	150.0	1120.0	N

LE VI.—FIFTH SERIES.

ON ROOF OF OFFICE BUILDING.

Weight before exposure, grams.	Chemical Analysis, per cent.						Average Loss per Square Inch of Surface, grams.			Average Loss per Annum in Thickness, each Surface, in.	Plate No.
							First Examination.	Second Examination.			
	Si	S	P	Mn	C	Zn	First Exposure, 120 days.	Second Exposure, 120 days.	First and Second Exposures, 240 days.		
509.5	No analysis. See analyses in other test series.						0.177	0.189	0.366	0.0043	001
1068.0	No analysis. See analyses in other test series						0.002	0.003	0.005	.....	002
1009.0	No analysis. Probably same as 050.						0.074	0.141	0.215	0.0025	003
1060.0	No analysis. Probably same as 046, 07, 017.						0.078	0.125	0.203	0.0024	004
1232.0	No analysis. Probably same as 010.						0.002	0.000	0.002	.....	005
549.5	No analysis. Probably same as 011, 013, 042, 044.						0.002	0.002	0.004	.....	006
1098.5	No analysis. See analyses in other test series.						0.177	0.150	0.327	0.0039	007
1145.5	No analysis. See analyses in other test series.						0.004	0.002	0.006	.....	008
1061.5	No analysis. Probably same as 070, 072.						0.184	0.112	0.296	0.0035	009
452.5	Copper 99.76. Trace of Arsenic.						0.000	0.000	0.000	.....	0010
85.25	Al. 98.5, Fe. 1.31, Silica 0.36.						0.005	0.000	0.005	.....	0011
2167.0	No analysis. Probably same as 051, 053.						0.228	0.168	0.396	0.0047	0012
1016.0	0.04	0.049	0.015	0.45	0.17	....	0.034	0.072	0.106	0.0013	0013
998.0	0.04	0.044	0.012	0.33	0.08	....	0.321	0.328	0.649	0.0077	0014
410.0	0.04	0.059	0.015	0.37	0.16	2.24	0.008	0.000	0.008	.....	0016

purposely introduced for rust resistance. See footnote to Table IV.
portion not protected and all losses are based on that figure.

LE VIII.—SIXTH SERIES.

UNNEL AND HIGH BRIDGE ENGINE-HOUSE SMOKE JACKS.

Weight before exposure, grams.	Chemical Analysis, per cent.							Average Loss per Square Inch of Surface, grams.			Average Loss per Annum in Thickness, each Surface, in.	Plate No.
								First Examination.	Second Examination.			
	Si	S	P	Mn	C	Zn	Silica	First Exposure, 120 days.	Second Exposure, 120 days.	First and Second Exposures, 240 days.		
	TUNNEL PLATES.											
479.0	No analysis. Probably same as 070 and 072.							0.201	0.716	0.917	0.012	043
471.5	No analysis. Probably same as 070 and 072.							0.270	0.759	1.029		045
65.0	No analysis. Probably same as 0011.							0.085	0.268	0.353	0.013	047
1267.0	Copper 99.76 per cent. Trace of Arsenic.							0.300	0.039	0.339	0.004	049
2014.0	....	0.040	0.270	None	0.07	....	0.33	0.378	1.030	1.408	0.015	051
1957.5	.. .	0.039	0.240	None	0.07	....	0.27	0.317	0.832	1.149		053
	SMOKE-JACK PLATES.							First Exposure, 60 days.	Second Exposure, 60 days.	First and Second Exposures, 120 days.		
602.0	Cu. 99.53 per cent. Trace of Arsenic.							0.473	0.292	0.765	0.014	074
629.5	Probably same as 074.							0.287	0.298	0.585		076
1120.0	No analysis. Probably same as 051 and 053.							0.500	0.367	0.867		078

Plate No.	Kind of Metal.	Dimensions, in.	Area of Surface, sq. in.	Weight before Exposure grams.
001	Special iron "B," plain	$5\frac{7}{8} \times 10\frac{7}{8} \times \frac{1}{16}$	129.9	509.5
002	Special iron "B," galvanized	$12 \times 12 \times \frac{1}{16}$	291.0	1068.0
003	Wrought iron plain (rolled from piled puddle iron)	$6 \times 12 \times \frac{1}{8}$	148.7	1009.0
004	Soft open-hearth steel, plain	$6 \times 11 \times \frac{1}{8}$	136.3	1060.0
005	Special non-ferrous metal, plain	$12 \times 12 \times \frac{1}{16}$	291.0	1232.0
006	Lead-coated galvanized steel	$6 \times 10\frac{3}{4} \times \frac{1}{16}$	131.1	549.5
007	Special iron "A," plain	$12 \times 12 \times \frac{1}{16}$	291.0	1098.5
008	Special iron "A," galvanized	$12 \times 12 \times \frac{1}{16}$	291.0	1145.5
009	Special steel "A," plain[1]	$12 \times 12 \times \frac{1}{16}$	291.0	1061.5
0010	Copper, plain	$4 \times 12 \times \frac{1}{16}$	98.0	452.5
0011	Aluminum, plain	$5\frac{5}{8} \times 8\frac{1}{2} \times \frac{1}{25}$	$\left\{\begin{matrix} 96.8 \\ 54.3^a \end{matrix}\right\}$	85.2
0012	Wrought iron, plain	$12 \times 12 \times \frac{1}{8}$	294.0	2167.0
0013	Steel from Railroad Co. stock "A," plain	$5\frac{1}{4} \times 10\frac{7}{8} \times \frac{1}{8}$	118.2	1016.0
0014	Steel from Railroad Co. stock "B," plain	$6 \times 11\frac{1}{16} \times \frac{1}{8}$	137.0	998.0
0016	Steel from Railroad Co. stock, galvanized	$5\frac{7}{8} \times 10\frac{15}{16} \times \frac{1}{16}$	130.6	410.0

[1] The special steel "A" was understood to have been manufactured with a percentage of copper purpose
[a] A portion of this plate is protected by a coating of paint. The lower figure is the area of the portio

TABLE VI

EXPOSED IN WEEHAWKEN TUNNEL

Plate No.	Kind of Metal.	Dimensions, in.	Area of Surface, sq. in.	Weight before Exposure grams.
043	Special steel "A," plain	$6 \times 11 \times \frac{1}{16}$	134.1	479.0
045	Special steel "A," plain	$6 \times 10\frac{15}{16} \times \frac{1}{16}$	133.4	471.5
047	Aluminum, plain	$5\frac{5}{8} \times 6\frac{1}{16} \times \frac{1}{25}$	69.1	65.0
049	Copper, plain	$11 \times 12 \times \frac{1}{16}$	266.9	1267.0
051	Wrought iron, plain	$11 \times 12 \times \frac{1}{8}$	269.8	2014.0
053	Wrought iron, plain	$11 \times 12 \times \frac{1}{8}$	269.8	1957.5
074	Copper, plain	$5\frac{3}{4} \times 10\frac{15}{16} \times \frac{1}{16}$	127.9	602.0
076	Copper, plain	$6 \times 10\frac{7}{8} \times \frac{1}{16}$	132.6	629.5
078	Wrought iron, plain	$6\frac{1}{16} \times 12 \times \frac{1}{8}$	150.0	1120.0
080	Wrought iron, plain	$5\frac{15}{16} \times 12 \times \frac{1}{8}$	147.0	1074.0
082	Aluminum, plain	Some error apparent in data for dimen		
084	Steel from Railroad Co. stock "A," plain	$5\frac{1}{4} \times 11\frac{1}{16} \times \frac{1}{8}$	120.2	881.0
086	Steel from Railroad Co. stock "B," plain	$6 \times 11 \times \frac{1}{8}$	136.3	993.5
088	Steel from Railroad Co. stock, galvanized	$6 \times 10\frac{7}{8} \times \frac{1}{16}$	132.6	408.0

Weight before Exposure, grams.	Si	S	P	Mn	C	Zn	First Examination. First Exposure, 120 days.	Second Examination. Second Exposure, 120 days.	Second Examination. First and Second Exposures, 240 days.	Annum in Thickness, each Surface, in.	Plate No.
509.5	No analysis. See analyses in other test series.						0.177	0.189	0.366	0.0043	001
1068.0	No analysis. See analyses in other test series						0.002	0.003	0.005	.....	002
1009.0	No analysis. Probably same as 050.						0.074	0.141	0.215	0.0025	003
1060.0	No analysis. Probably same as 046, 07, 017.						0.078	0.125	0.203	0.0024	004
1232.0	No analysis. Probably same as 010.						0.002	0.000	0.002	.....	005
549.5	No analysis. Probably same as 011, 013, 042, 044.						0.002	0.002	0.004	.....	006
1098.5	No analysis. See analyses in other test series.						0.177	0.150	0.327	0.0039	007
1145.5	No analysis. See analyses in other test series.						0.004	0.002	0.006	.....	008
1061.5	No analysis. Probably same as 070, 072.						0.184	0.112	0.296	0.0035	009
452.5	Copper 99.76. Trace of Arsenic.						0.000	0.000	0.000	.....	0010
85.25	Al. 98.5, Fe. 1.31, Silica 0.36.						0.005	0.000	0.005	.....	0011
2167.0	No analysis. Probably same as 051, 053.						0.228	0.168	0.396	0.0047	0012
1016.0	0.04	0.049	0.015	0.45	0.17	....	0.034	0.072	0.106	0.0013	0013
998.0	0.04	0.044	0.012	0.33	0.08	....	0.321	0.328	0.649	0.0077	0014
410.0	0.04	0.059	0.015	0.37	0.16	2.24	0.008	0.000	0.008	.....	0016

opper purposely introduced for rust resistance. See footnote to Table IV.
of the portion not protected and all losses are based on that figure.

Table VIII.—Sixth Series.

KEN Tunnel and High Bridge Engine-House Smoke Jacks.

Weight before Exposure, grams.	Si	S	P	Mn	C	Zn	Silica	Average Loss per Square Inch of Surface, grams. First Examination. First Exposure, 120 days.	Second Examination. Second Exposure, 120 days.	Second Examination. First and Second Exposures, 240 days.	Average Loss per Annum in Thickness, each Surface, in.	Plate No.
Tunnel Plates.												
479.0	No analysis. Probably same as 070 and 072.							0.201	0.716	0.917	0.012	043
471.5	No analysis. Probably same as 070 and 072.							0.270	0.759	1.029		045
65.0	No analysis. Probably same as 0011.							0.085	0.268	0.353	0.013	047
1267.0	Copper 99.76 per cent. Trace of Arsenic.							0.300	0.039	0.339	0.004	049
2014.0	....	0.040	0.270	None	0.07	....	0.33	0.378	1.030	1.408	0.015	051
1957.5	.. .	0.039	0.240	None	0.07	....	0.27	0.317	0.832	1.149		053
Smoke-Jack Plates.								First Exposure, 60 days.	Second Exposure, 60 days.	First and Second Exposures, 120 days.		
602.0	Cu. 99.53 per cent. Trace of Arsenic.							0.473	0.292	0.765	0.014	074
629.5	Probably same as 074.							0.287	0.298	0.585		076
1120.0	No analysis. Probably same as 051 and 053.							0.500	0.367	0.867	0.018	078
1074.0	No analysis. Probably same as 051 and 053.							0.282	0.408	0.690		080
ata for dimension. Plate lost in stack; was badly corroded in first exposure. No analysis; probably same as 0011.												082
881.0	0.04	0.049	0.015	0.45	0.17	....	....	0.549	0.374	0.923	0.022	084
993.5	0.04	0.044	0.012	0.33	0.08	....	....	0.631	0.429	1.060	0.025	086
408.0	0.04	0.059	0.015	0.37	0.16	2.24	.. .	0.403	0.373	0.776	0.018	088

mill scale by the end of the second exposure, while many other plates had much mill scale intact, the plain ferrous plate which showed the least corrosion having scale remaining on at least 50 per cent of the surface of one side, this being scattered in small patches or tortuous lines with rusted metal between. It is the intention to experiment with ferrous specimens from which the mill finish and scale has been removed by pickling, in the endeavor to determine the effect thereof.

One other series of corrosion tests which is in progress may be found interesting. This is a small series instituted mainly to learn something of the effect of gaseous atmospheres on copper and aluminum. Specimens of these metals together with others

TABLE VII.—FIFTH SERIES, WEATHER TESTS. PLAIN FERROUS METAL SPECIMENS ONLY. 240 DAYS EXPOSURE.

Relative Order of Resistance.	Kind of Metal.	Calculated Rate of Corrosion per Annum in Thickness per Surface, in.
1	Steel from Railroad Co. stock "A," plain plate	0.0013
2	Soft open-hearth steel, plain plate	0.0024
3	Wrought iron, plain plate	0.0025
4	Special-steel "A," plain plate	0.0035
5	Special-iron "A," plain plate	0.0039
6	Special-iron "B," plain plate	0.0043
7	Wrought iron, plain plate	0.0047
8	Steel from Railroad Co. stock "B," plain plate	0.0077

of steel and iron were exposed in the Weehawken tunnel and in the High Bridge engine-house. The data and the results for the two exposures of this series are shown herein in Table VIII (Plate XVIII).

It will be noted that in the tunnel the rate of corrosion of the aluminum was about a mean between those of the steel and the wrought iron. After the last exposure in the tunnel the aluminum specimen presented a badly disintegrated appearance, the surface being roughened and corroded most unevenly. The plate shows a progressively increasing deterioration from the edge which was towards the blower, and which is not much reduced, to the other edge which was worn to a sharp, irregular line. In the engine-house the aluminum plate was badly corroded during the first exposure and disappeared during the

second exposure; the rate of corrosion in the first exposure could not be properly given because it was evident from a subsequent examination of the data that either the original dimensions or weight had been wrongly recorded, and when this was discovered the plate had been lost and the dimensions could no longer be checked.

The rate of corrosion of the copper was about the same as that of the aluminum in the first tunnel exposure, but strangely dropped to a small fraction of the same for the second exposure. In the engine-house the rate was lower than any of the other metals, but not greatly so, and the rate was sustained in the second exposure in about the same proportion as for the other metals.

It is the intention to continue the third and fourth series, tunnel tests, and the weather tests, and to add additional series from time to time in order to check the results already obtained and to gain information regarding other kinds of metals and coatings.

Acknowledgments are due to Mr. R. W. Mahon, Chemist and Engineer of Tests of the New York Central and Hudson River Railroad Co., and a member of the Society, for the chemical analyses herein recorded.

DISCUSSION.

MR. A. S. CUSHMAN.—I do not wish to approach the discussion of Mr. Carpenter's paper in a controversial spirit, but I simply wish to repeat what I have stated in a number of discussions of corrosion problems from time to time during the last seven or eight years, that any method of attempting to determine the relative resistance to corrosion of different test pieces under different conditions of exposure which depends upon measuring the loss in weight per unit area of the samples under test, is so misleading that, in my opinion, it leads in very many cases to conclusions absolutely opposite from the actual truth. A sample which under a given condition of exposure loses weight very evenly all over its surface as granular rust, may be the best plate in the test; whereas, another sample suffering from segregated corrosion is being damaged badly, although the loss in weight may be, comparatively speaking, an insignificant factor. If, let us say, from a smooth metallic surface a certain given weight of material was to be taken off for some purpose or other, it would be possible to remove this weight by planing off the surface, and yet the specimen would have been damaged perhaps not at all; whereas, if the same metallic surface were attacked with a drill in order to get an equal weight of material, the specimen might be utterly destroyed for any purpose. Therefore, I believe that far-reaching conclusions are not justified as based upon tests such as those described in this paper. **Mr. Cushman.**

It may be said, too, that except in a very limited way, people do not purchase light-gage ferrous material without some form of protective coating for exposure to corrosive conditions; therefore the testing of bare, thin-gage material is to some extent an artificial acceleration test. A point which is frequently lost sight of in the study of corrosion problems is that only the material immediately on the surface is involved in the corrosion. If we are testing a plate $\frac{1}{2}$ in. thick

Mr. Cushman. to see how it will withstand corrosion, it makes no difference what the condition may be in the interior of the plate; it is the condition of the surface immediately exposed that really matters. If we expose test pieces with mill scale on them, they should all be exactly alike in order to enable us to draw conclusions from short-time tests, and that seems to me to be impossible of accomplishment.

As Mr. Carpenter found out, and as I would have predicted, after his first exposure the losses were extraordinarily high on some of the samples, but on the second and third exposure those losses toned down and became less and less. That is exactly what one would expect from mill-scale surfaces on light-gage test pieces.

Mr. Ormsbee. MR. J. M. ORMSBEE.—May I ask how these samples were prepared before testing? Were they brushed or treated in any way?

Mr. Carpenter. MR. A. W. CARPENTER.—The samples were exposed just as they came from the parties who furnished them; there was no preparation of the surfaces whatever, no coating of the surfaces. Of course the ferrous metals all had mill scale, which, as I recall, was practically perfect on the surface in all cases.

Mr. Voorhees. MR. S. S. VOORHEES.—I notice that in all of these analyses, the copper is stated as not being present. That is rather unusual. From analyses of a good many steels, I think we never failed to find copper in certain small amounts ranging from a few thousandths of one per cent up to higher percentages, and I should like to ask Mr. Carpenter what those copper percentages signify which are reported as none?

Mr. Carpenter. MR. CARPENTER.—That is the report of Mr. R. W. Mahon, Chemist, New York Central and Hudson River Railroad Co., and a member of the Society, who unfortunately is not present; it is what he reported that he found. I would not say there was absolutely no copper; but Mr. Mahon reported finding none. Whether he found traces of copper, I can not say.[1]

Mr. Karr. MR. C. P. KARR.—The first sample of the third series was made of copper and nickel; I should like to ask whether this was some alloy of copper and nickel?

[1] See notes to Table IV, p. 621.—ED.

MR. CARPENTER.—Mr. President, I have not mentioned the name of any special metal; would it be proper to do so under the circumstances? **Mr. Carpenter.**

THE PRESIDENT.—I think that should be left to your own judgment, sir. **The President.**

MR. CARPENTER.—The chemical analysis that is shown is the analysis of a plate supposed to be made from a natural ore. **Mr. Carpenter.**

MR. R. H. GAINES.—I should like to ask Mr. Carpenter if he has reached any definite conclusions as the result of these experiments? **Mr. Gaines.**

THE PRESIDENT.—I think we are proceeding a little informally in putting these interrogations categorically. They ought to be presented and then Mr. Carpenter should be given an opportunity to reply at the conclusion of the discussion. **The President.**

MR. J. A. CAPP.—I should like to call attention to the fact that in most of the tables the number of specimens tested is stated as one and in some of them as two. I should like to ask if it is not relatively risky to draw broad conclusions from one or two specimens of a material which is pretty well noted for the variety of the results it gives if the tests are made on a number of specimens. **Mr. Capp.**

MR. CLOYD M. CHAPMAN.—I should like to ask if any record has been made, either photographic or descriptive, of the character of the surface as to pitting or irregularities, left after the corrosion had been removed. **Mr. Chapman.**

THE PRESIDENT.—Is there anything further, gentlemen? If not, will Mr. Carpenter kindly make such reply as he pleases in concluding the discussion? **The President.**

MR. CARPENTER.—Referring to Mr. Cushman's remarks, I should like to state that I agree with a good deal that he says; but in regard to the criticism on the figures as representing the rate of corrosion correctly, I desire to state that the corrosion was remarkably even over the surfaces of all of the specimens with the exception of those mentioned in the paper, and especially the non-ferrous metal plate—the copper and nickel plate—in the gaseous atmosphere. That plate, as I remarked in the paper, pitted deeply in the first exposure; the surface was pock-marked, **Mr. Carpenter.**

Mr. Carpenter. and the main loss of the plate was apparently due to what was eaten out in those pock-marks; after that there was very little loss in the plate. In that case and perhaps in the one or two other cases of uneven corrosion mentioned in the paper, the loss of weight per unit area of surface was not alone a sufficient measure of the corrosion, for which reason the action of the corrosion in those cases was particularly described; but in the other cases, I believe that any one seeing the plates after exposure would agree that the loss-of-weight method was a very satisfactory one. I have three or four plates of the first series with me, and it may possibly be of some interest to examine them.

In regard to the mill scale, I have partially answered that question. We did not, ourselves, until very lately, appreciate the effect of mill scale on corrosion to be so important as it has recently been pointed out, and I stated in the paper that we hope to make some tests on specimens with mill scale removed. However, the mill scale was practically all gone after the first one or two exposures in the gaseous atmospheres, so that thereafter there was no further mill-scale protection—I refer of course to the plain ferrous specimens. As to the condition of the surfaces, that can be partially noted from the plates that I have. We kept a descriptive record but no photographs. However, we have nearly all the plates.

As to the value of the tests, it would seem that some definite information as to the rates of corrosion of the different kinds of metals, and as to the value of the different coatings, has been established. The work has been done carefully by parties not interested in the production of the materials, which were treated with absolute impartiality, and has been carried out under service conditions. While the limitations as to the number and sizes of test pieces are recognized and the conditions of exposure of some tests were far from being as satisfactory as desired, it is felt that the results are fairly reliable, comparable, and representative of the materials.

The method of measuring the corrosion seems to be the only practical one, and while involving some assumptions, as has been pointed out, it would seem that in the case of prac-

tically uniform corrosion of the surfaces such as occurred in these tests, with the few exceptions noted and fully described, it must be accepted as a sufficiently accurate method, and since it is a definite, mathematical method, involving no exercise of personal judgment or opinion, it would seem that this feature should meet with the approval of scientists in general. **Mr. Carpenter.**

LEAD-TIN-ANTIMONY AND TIN-ANTIMONY-COPPER ALLOYS.

By William Campbell.

Until a comparatively recent time, "the constitution and properties of alloys" was considered to be a subject of great mystery. Workers in metals and alloys were thought to possess secrets and formulas which were carefully guarded from the outside world. To-day, thanks to the physical chemist and the metallographist, most of these mysteries have been cleared up and we understand the constitution of alloys and can correlate this knowledge with the results on physical properties obtained through scientific research in the testing of materials.

The constitution of binary alloys can best be shown by the temperature-composition or thermal diagram, which shows not only the changes which take place when an alloy passes from the liquid to the solid condition but also the changes which occur in the solid state.

The binary thermal diagrams have been collected by Portevin[1] and by Bornemann.[2] Guertler's text-book of metallography discusses them exhaustively, while for the beginner, the theory is very clearly set forth in Desch's "Metallography" and Gulliver's "Metallic Alloys," 1913 edition.

The alloys of lead-tin-antimony and tin-antimony-copper are of such importance in the arts as bearing-metal, type-metal, white metal for small castings, etc., that a discussion of their constitution may not be out of place. Further, in order to make clear the two ternary diagrams, a brief outline will be given of the chief types of diagrams and their meaning.

Binary Alloys.

The physical chemist has shown us that alloys are solutions and can be classified according to their solubility both in the liquid and solid states.

[1] *Revue de Metallurgie*, 1908, pp. 144, 182, 274, 360, 534, 762, 838, 909; 1909, pp. 241, 951, 963, 975.

[2] Die binären Metallegierungen, 1909, 1912.

In brief we may classify binary alloys as follows:

A.—NO COMPOUNDS ARE FORMED.

1.—Completely soluble in the liquid state.....
- (*a*) Completely soluble in the solid state.
- (*b*) Partially soluble in the solid state.
- (*c*) Insoluble in the solid state.

2.—Partially soluble in the liquid state.....
- (*b*) Partially soluble in the solid state.
- (*c*) Insoluble in the solid state.

3.—Insoluble in the liquid and insoluble in the solid state.

B.—COMPOUNDS ARE FORMED.

1.—The compound occurs at a maximum on the freezing point curve.

2.—The compound dissociates before reaching its melting point or, in cooling, forms by the reaction between one of the metals and the liquid from which it has crystallized.

We can make a further classification according to the solubility of the compound in the two metals as above.

In the case of the alloys of the metals under discussion, the solubility in the liquid state is complete, and the type thermal diagrams are given in Fig. 2.

The thermal diagram is constructed from the temperature-time or cooling curves of individual alloys, the main types of which are given in Fig. 1. These curves show the changes in the rate of cooling as an alloy cools from the liquid down into the solid state. Curve I is that of a pure metal which cools in the liquid state regularly from *a* to *b*. At *b* the metal commences to freeze and the temperature remains constant due to the latent heat of fusion, until at *c* the metal is completely solid. From *c* to *d* the metal cools regularly in the solid state. The other curves illustrate the freezing of different alloys.

Now by taking a number of alloys of two metals and plotting the breaks in their cooling curves on a temperature-composition diagram, the thermal diagram can be constructed and we can draw curves showing the beginning of freezing or the "liquidus," and the end of freezing or the beginning of melting, called the

"solidus," curves. Then between these two curves the metal consists of a mixture of liquid and solid. In addition, the liquidus gives the composition of the liquid at any particular temperature, while the solidus gives the composition of the solid freezing out at that temperature. So changes in composition of the liquid and solid are given by the liquidus and solidus respectively.

Let us consider first the alloys of two metals which do not form a compound.

Case A–1–(a): Completely soluble in both the liquid and solid states.—Temperature being given in the vertical scale and

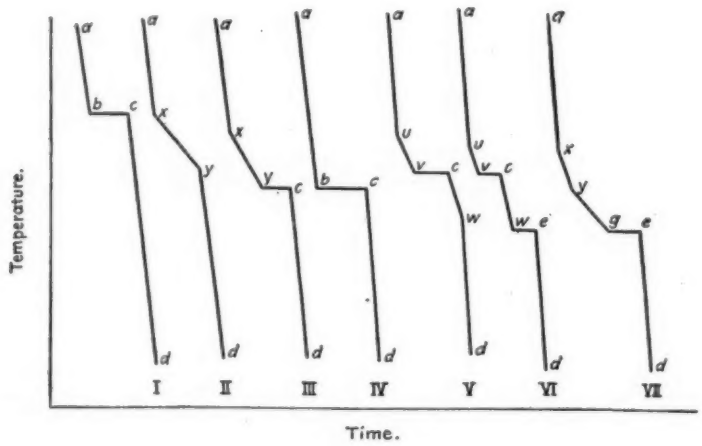


FIG. 1.—Type Cooling Curves.

percentage composition in the horizontal, *A* in Curve I, Fig. 2, is the freezing point of the pure metal A and *B* that of the pure metal B. The freezing point of any alloy of A and B is given by the liquidus or *A x B;* the melting point by the solidus *A y B*. Each alloy has a freezing point or cooling curve similar in shape to Curve II, Fig. 1, where the alloy begins to freeze at *x* and is completely solid at *y*. For example, in Curve I, Fig. 2, the alloy indicated by the vertical line through *x y*, begins to freeze on reaching the point *x* on the liquidus. Pure metal A does not freeze out, but is a solid whose composition is given by the solidus curve for this temperature, namely *m*. Now as

freezing continues, the composition of the liquid follows the liquidus from x to n; that of the solid changes from m to y on the solidus curve, so that when completely solid the alloy has the composition y and consists of homogeneous grains of a solid solution of A and B by diffusion, while the last drop of liquid to freeze out had the composition n.

Thus the alloys of A and B, when solid, consist of a series of solid solutions of A and B, or *alpha*, which are continuous from pure A to pure B and vary uniformly in physical properties.

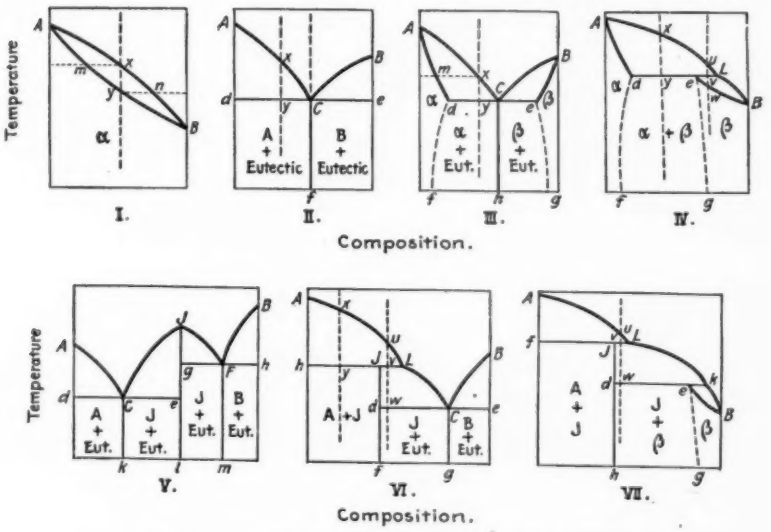


FIG. 2.—Type Thermal Diagrams of Binary Alloys.

As examples of such a series, we have nickel-copper, gold-silver, iron-manganese, etc.

Case A-1-(c): The two metals are completely soluble in all proportions in the liquid state, but are insoluble in each other in the solid state.—The thermal diagram is shown in Curve II, Fig. 2. The addition of B to A or A to B lowers the freezing point progressively and we have two curves, $A\,C$ denoting the freezing out of A and $B\,C$ the freezing out of B, which intersect at a point C. The alloy C, being the alloy with the lowest freezing point, is called the "eutectic." Above $A\,C\,B$, the liquidus,

the alloys are completely liquid; below the line *d C e*, the solidus, they are completely solid; while in the area *A C d*, we have crystals of A in a liquid whose composition is given by the curve *A C*. In the area *B C e* we have crystals of B in a liquid, the composition of which is given by the *B C* branch of the liquidus. In the area below the solidus, *d C f*, we have crystals of A surrounded by a ground mass composed of a mechanical mixture of A and B, or the eutectic. In the area *e C f* we have crystals of B surrounded by the eutectic. The alloy *C f* which freezes at the intersection of the branches of the liquidus *A C* and *B C*, denoting the simultaneous freezing of A and B, consists of a mechanical mixture of A and B therefore, which is the eutectic.

Consider the alloy represented by the vertical line *x y*. On cooling down to the point *x* on the liquidus *A C*, pure A begins to freeze out and the composition of the liquid follows the liquidus from *x* to *C*. On reaching the temperature *y* the residual liquid has the composition *C* and freezes as a mechanical mixture of A and B, the eutectic.

The time-temperature curve of such an alloy is shown in Curve III, Fig. 1. From *a* to *x* the alloy is liquid, from *x* to *y* the metal A is freezing out, from *y* to *c* the eutectic freezes and from *c* to *d* the alloy cools regularly in the solid state.

In Curve II, Fig. 2, the eutectic alloy, represented by the vertical line *C f*, begins and ends freezing at the constant temperature *C*. Its time-temperature curve is shown in Curve IV, Fig. 1, *a* to *b* representing uniform cooling in the liquid, *b* to *c* freezing at a constant temperature, *c* to *d* uniform cooling in the solid state.

We may take lead-antimony as an example.

Case A-1-(b): The two metals are partially soluble in each other when solid. A eutectic occurs.—The curve is given in Curve III, Fig. 2, and has a liquidus similar to the last case. The solidus or end of freezing is given by *A d C e B*, which shows that the eutectic only exists between *d* and *e*, because the metal A will hold a maximum of *d* per cent of B in solid solution, while B will hold a maximum of *e* per cent of A in solid solution. Thus alloys up to *d* per cent of B and *e* per cent of A consist of solid solutions, which we may call alpha and beta respectively, and freeze as in Case *A-1-(a)*. Alloys with more B or more A

than these limits show a eutectic which is a mechanical mixture of alpha and beta, and not A and B. Alloys within this range may be represented by the alloy *x y*, which on cooling from the liquid state begins to freeze at *x* by separating out a solid, whose composition is given by the solidus curve *A d*, namely *m;* and as freezing continues the composition of the liquid changes from *x* to *C*, and that of the solid from *m* to *d*. On reaching the temperature *y*, we have solid alpha of composition *d* and the liquid C, which then freezes as a mechanical mixture of alpha and beta, the eutectic. Hence, below *d C* we have crystals of alpha surrounded by the eutectic. Alloys below *C e* consist of crystals of beta surrounded by the eutectic.

The curves *d f* and *e g* are the *solubility curves* of B in A and A in B in the solid state and show decrease in solubility with fall of temperature.

To be quite correct the diagram ought to show the α + Eutectic area only below *d y*, while the area below *d f* ought to be labeled $\alpha + \beta$. Similarly, the area below *e g* ought to be $\beta + \alpha$. As the eutectic is composed of a mechanical mixture of α and β, the most simple way is to call the whole area *f d e g*, $\alpha + \beta$.

As examples of this group we have copper-silver, bismuth-tin, bismuth-lead, tin-lead, etc.

Case A-1-(b): The two metals are partially soluble in each other when solid, but no eutectic occurs.—Curve IV, Fig. 2, shows that the addition of B to A lowers the freezing point, while the addition of A to B raises it, producing two branches of the liquidus which intersect at the point *L*. The solidus curve is *A d e B*. As before, alloys containing up to *d* per cent of B or *e* per cent of A consist of solid solutions, namely alpha and beta. Between *d* and *e*, when solid, the alloys consist of grains and crystals of alpha in a ground mass of beta. For an alloy represented by the vertical line *x y* begins to freeze out solid alpha on reaching the liquidus at *x* as in the last case, and the composition of the solid follows the solidus curve *A d* to *d*, while the liquid changes from *x* to *L*. At the temperature *y*, the alloy consists of solid alpha of composition *d* and the liquid L. Then we have the formation of solid beta by a reaction between the liquid L and the solid alpha and the temperature remains con-

stant until all of the liquid is used up and the alloy is completely solid; alpha in a ground mass of beta.

The time-temperature curve of such an alloy is given in Curve III, Fig. 1, where *x y* represents the freezing out of solid alpha and *y c* the reaction between this alpha and the liquid L to form beta.

In the case of the alloys whose composition lies between *e* and *L*, the solid alpha is all used in the reaction before the liquid L has disappeared; hence the resulting solid consists of beta alone, the composition of which is given by the branch *e B* of the solidus. Thus, in the case of the alloy represented by the vertical line *u v w*, solid alpha begins to separate out when the temperature reaches the liquidus at *u* as before and continues to freeze out down to the temperature *v*. At this point we get the reaction, alpha of composition *d* plus liquid L, forming beta of composition *e*, which continues until all of the alpha has disappeared. The temperature then falls, the composition of the liquid following the liquidus *L B*, while that of the solid changes from *e* to *w*, when the whole mass is solid and consists of the solid solution beta.

The time-temperature curve of such an alloy is given in Curve V, Fig. 1. The branch *u v* shows the separation of the solid alpha, the horizontal *v c* the reaction between alpha and the liquid at a constant temperature, while the branch *c w* shows the further separation of beta with fall of temperature ending in complete solidification at *w*.

As examples we have cadmium-mercury, platinum-silver, copper-iron, the brasses, and the bronzes.

Returning to Curve IV, Fig. 2, the lines *d f* and *e g* show the change of solubility of B in A and A in B in the solid state with fall of temperature.

Consider next the alloys of two metals which form a compound.

Case B-1: The compound occurs at a maximum on the freezing-point curve.—The simplest case is where the compound of A and B or J is insoluble in the solid state in either A or B. We therefore get two simple curves like Curve II, Fig. 2, the alloys of A and J and the alloys of B and J. Such a curve is shown in Curve V, Fig. 2, where the compound J forms a eutectic *C* with

A and a eutectic *F* with B. The method of freezing is the same as described under Case *A-1-(c)* or Curve II, Fig. 2.

As examples, we may take zinc-magnesium, lead-magnesium, copper-phosphorus, and copper-arsenic.

Case B-2: The compound dissociates before reaching its melting point, or in cooling, forms by reaction between one of the solid metals and the liquid from which it has crystallized.—The thermal diagram is shown in Curve VI, Fig. 2, where *A L C B* is the liquidus, *A h J d C e B* the solidus. The point *C* is the eutectic, a mechanical mixture of the compound J and B. Then alloys from pure *A* to *J* consist of A in a ground mass of J; alloys from *J* to *C* (or *f* to *g*) consist of the compound J surrounded by the eutectic; while from *C g* to pure *B* they consist of B surrounded by the eutectic. The alloy *x y*, representing the first type, begins to freeze out pure A on reaching the liquidus at *x*, and as A continues to freeze out, the composition of the liquid becomes richer and richer in B, following the liquidus from *x* to *L*. On reaching the point *y*, the solid A reacts with the liquid L to form the compound J and the temperature remains constant until all of the liquid L has been used up. The resulting alloy therefore consists of cores of A surrounded by a ground mass of the compound J.

The time-temperature curve of such an alloy is given in Curve III, Fig. 1, where *x y* indicates the freezing of pure A and *y c* the reaction at constant temperature to form the compound J.

In the case of the alloys whose composition lies between *J* and *L*, all of the solid A is used up before the liquid L. Thus, in the alloy represented by the line *u v w*, from *u* to *v* the pure metal A freezes out. At *v* the reaction occurs as before, but all of the A is used. The remaining liquid L then freezes by separating out the compound J, and changes in composition from *L* to *C* as the temperature falls from *v* to *w*. Here the residual liquid of the composition C freezes as a eutectic of J and B.

The time-temperature curve of this alloy is given in Curve VI, Fig. 1, where *u v* represents the freezing out of the solid A, *v c* the reaction to form the compound J. At *c* all of the A has

disappeared and J continues to freeze out from *c* to *w*. Finally *w e* shows the freezing of the eutectic of J and B.

Alloys between *L* and *C* freeze normally by separating out the compound J, until at the temperature *d C e* the residual liquid of composition C freezes as the eutectic. Alloys from the eutectic C to pure B freeze as already described.

Various modifications of these type curves could be drawn, showing partial solubility of the compound J in both A and B, and *vice versa*, the freezing taking place as in the cases already discussed.

One case may be mentioned as bearing on the alloys under discussion; namely, where J and B do not form a eutectic, J being partially soluble in B. This is shown in Curve VII, Fig. 2.

Alloys from pure *A* to *J* freeze as before. Alloys from *J* to *L* show the reaction whereby all of the A is used up before the liquid L. Thus in the alloy *u v w*, A freezes out from *u* to *v;* then the reaction follows and A disappears, when the temperature falls with the separation of more J, until at *w* we have the compound J and the liquid K. Further freezing occurs as in Curve IV, Fig. 2, substituting J for alpha, for at *w* we have the reaction between J and the liquid K to form beta of the composition *e*. This continues until all of the liquid K is used up and the resulting alloy consists of J surrounded by the solid solution beta.

The time-temperature curve is given in Curve VI, Fig. 1, where *u v* represents the freezing out of the pure metal A, *v c* the reaction of A with the liquid L to form the compound J; *c w* shows the further separation of J while the horizontal *w e* denotes the reaction between J and the liquid K to form saturated beta of composition *e*. Alloys to the right of *L*, Curve VII, Fig. 2, freeze as already described, substituting J for alpha.

As an example of this type we have the alloys of tin and antimony.

TERNARY ALLOYS.

The simplest method of representing a series of ternary alloys is by means of an equilateral triangle. In Fig. 3, the corners of the triangle represent the pure metals A, B and C. The binary alloys of A and B are located on the line *A B* which

is a projection of such curves as are shown in Fig. 2. The binary alloys of B and C and of A and C are represented by the lines *B C* and *A C*, respectively. An alloy of all three metals is represented by a point within the triangle, for the sum of the perpendicular distances from any point within the triangle to the three sides is constant and is taken as equal to 100 per cent.

Take the alloy represented by the point *g* in Fig. 3: the percentage of A is given by the perpendicular from *g* to *B C*, the percentage of C by the perpendicular from *g* to *A B*, while the percentage of B is given by the perpendicular from *g* to *A C*. If we wish to indicate temperature the scale must be perpendicular to the plane of the triangle and we must construct a solid figure.

Case I.—The simplest case is that in which each pair of

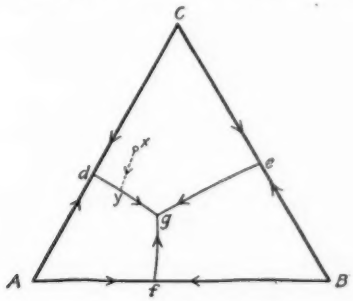


FIG. 3.—Ternary Diagram.

metals has a curve similar to Curve II, Fig. 2. That is, when the pairs are *completely soluble in the liquid state and insoluble in the solid*. This is shown in Fig. 3. The side *A B* is the projection of Curve II, Fig. 2, and the point *f* is the binary eutectic of A and B corresponding to the alloy *C f* in Curve II, Fig. 2. The fall of temperature is indicated by the arrows. Similarly, *d* is the binary eutectic of A and C, and *e* the binary eutectic of B and C. The point *g* is the ternary eutectic and is the lowest temperature on the diagram.

Within the area *A d g f* the metal A freezes out first; within the area *B f g e*, B is the first to form; while in the area *C d g e* the metal C separates out first.

For example, the alloy corresponding to *x* begins to solidify by separating out pure C and the composition of the liquid

changes from x to y (a projection through C). On reaching y the metal A begins to freeze, and A and C freeze out together, while the liquid changes from y to g. On reaching g, the residual liquid freezes out as a mechanical mixture of A, B and C, the ternary eutectic. Other alloys freeze similarly, the line $d\,g$ denoting the simultaneous freezing of A and C, the line $e\,g$ the binary B and C, while fg is the binary A and B.

Charpy[1] has worked out the lead-tin-bismuth diagram, Stoffel[2] the diagrams for lead-tin-cadmium and bismuth-tin-cadmium.

In Fig. 3, suppose C represents bismuth, A represents tin and B represents lead. Then in the alloy x, bismuth will freeze first while the liquid changes from x to y. From y to g, bismuth and tin will freeze out side by side on the already formed crystals of bismuth, and when the liquid reaches g the ternary eutectic of lead, bismuth and tin will freeze. Fig. 16 will represent such an alloy. The white cubes are the bismuth crystals which first formed. The half-tone envelopes around them are the binary bismuth-tin, while the black ground mass is the ternary eutectic.

The time-temperature curve of such an alloy is shown in Curve VII, Fig. 1, where $x\,y$ denotes the freezing of the metal C (bismuth) from x to y on Fig. 3; $y\,g$ denotes the simultaneous freezing of bismuth and tin (C and A) in Fig. 3 from y to g; while $g\,e$ is the freezing of the ternary eutectic of bismuth, tin and lead (C, A and B) at the point g in Fig. 3.

Fig. 17 would represent an alloy of composition y, Fig. 3, the half-tone masses being the binary A and C or tin and bismuth, the dark ground mass the ternary eutectic as before.

More complicated cases have been worked out by Geer,[3] and by Sahmen and Vegesack,[4] of which three are now given.

Case II.—The two metals A and B and the two A and C form eutectics as in Curve II, Fig. 2, but C and B show a reaction as in Curve IV, Fig. 2. Such a ternary system is shown in Fig. 4, where d is the eutectic of A and C, f is the eutectic of A and B,

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[1] *Metallographist*, Vol. II, p. 26 (1899).
[2] *Zeitschrift für anorganische Chemie*, Vol. 53, p. 137.
[3] *Journal of Physical Chemistry*, Vol. VIII, p. 237 (1904).
[4] *Zeitschrift für physikalische Chemie*, Vol. 59, p. 257 (1907).

while *e* corresponds to the point *L*, Curve IV, Fig. 2, the reaction point. Then the line *e g* shows the reaction between the C-rich solid solution and the liquid *e g* to form the B-rich solid solution, as in Curve IV, Fig. 2. At the point *g*, Fig. 4, we do not get a ternary eutectic but a reaction between the C-rich solid solution and the liquid *g* to form the B-rich solid solution and solid A. Assuming that the eutectic *f* freezes at a lower temperature than the eutectic *d*, then *f* will be the lowest temperature on the diagram and therefore the eutectic of the whole series, for as we get a continuous slope from *C* through *e* to *B*, *g f* will slope to *f*, and will represent the simultaneous freezing of A and the B-rich solid solution.

For example, take the alloy *x*, Fig. 4. On freezing, pure

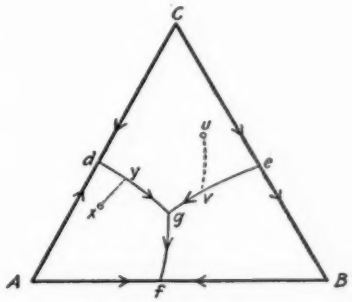


FIG. 4.—Ternary Diagram.

A will crystallize out and the liquid will change from *x* to *y*. Next, we shall have the binary A and C (containing increasing amounts of B in solid solution) freezing out and the liquid passing from *y* to *g*. At *g* occurs the reaction between C and the liquid *g* to form the B-rich solid solution plus A. This continues until all of the liquid or all of the C is used. If all of the liquid is used then the alloy becomes solid at *g*. If all of the C is used, then freezing continues, with the simultaneous freezing of A and B (containing C in solid solution in decreasing amounts), and the liquid follows the line *g f*.

Now with the alloy *u*, Fig. 4, the first solid to form is C, containing B in solid solution in amounts increasing as the temperature falls and the liquid passes from *u* to *v*. On reaching

the curve *e g* at *v*, the reaction takes place between the C-rich solid solution and the liquid, producing the B-rich solid solution, and this continues as the liquid changes from *v* to *g*. At *g* we get the reaction as above described.

An alloy within the area *e g f B* will start to freeze by separating out the B-rich solid solution, and the liquid will finally reach the curve *g f* when the simultaneous freezing of A and the B-rich solid solution will occur as before.

Case III.—The two pairs A and C, and B and C, form eutectics as in Curve II, Fig. 2, but A and B form a compound J which does not occur at a maximum on the freezing point curve, as in Curve VI, Fig. 2. The ternary diagram is shown in Fig. 5, where *d* is the eutectic of A and C, *e* is the eutectic of B and C,

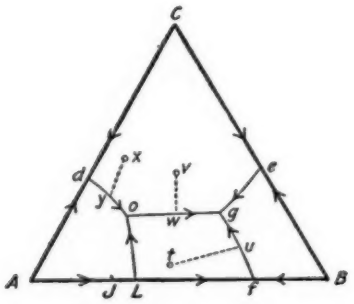


FIG. 5.—Ternary Diagram.

g is the ternary eutectic of C, B and J, and *o* is a reaction point where solid A plus liquid *o* react to form the compound J plus solid C.

Within the area *A L o d* the metal A crystallizes first, within the area *C d o g e* the metal C is the first to freeze, while in the area *L o g f* the compound J forms first, and in the area *B f g e*, the metal B first crystallizes. Then *d o* represents the simultaneous freezing of A and C, *e g* that of B and C, *f g* that of J and B, while *o g* is that of J and C. The curve *L o* is a reaction line, A plus liquid *L o* equals J.

The alloy *x* on reaching its freezing point begins to separate out crystals of C, which continue to form while the liquid changes from *x* to *y*. On reaching *y* there is a simultaneous solidification

of A and C, which continues while the liquid changes from *y* to *o*. At *o* occurs the reaction between A and the liquid *o* to form the compound J plus C. If the liquid is all used before the metal A, then the alloy becomes solid at *o*. If the metal A is used before the liquid *o*, freezing continues with fall of temperature by the simultaneous freezing out of J and C, the composition of the liquid following the curve *o g* until the ternary eutectic is reached at *g*, when the residual liquid freezes as a mechanical mixture of J, C and B.

The alloy *v* begins to freeze by separating out the metal C and the liquid follows *vw* to *w*, where the simultaneous freezing of J and C begins as before, and the liquid changes from *w* to *g*, the ternary eutectic as above.

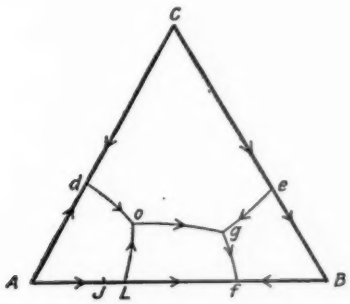


FIG. 6.—Ternary Diagram.

The alloy *t*, on reaching its freezing point, begins to solidify by separating out the compound J, and the liquid changes in composition from *t* to *u* as J continues to form. At *u* the binary separation of J and B begins and the liquid then follows *u g* to *g*, the ternary eutectic.

Alloys in the other areas freeze as already described.

Case IV.—The metals A and C form a eutectic; A and B form a compound J as in Case III; the metals C and B show no eutectic, but a reaction point as in Curve IV, Fig. 2.

In Fig. 6, the freezing takes place as already described, but the point *g* is a reaction point as in Fig. 4, and not the ternary eutectic. Hence, *f* is the lowest point on the diagram and is therefore the eutectic of the series.

In short, *d o* is the binary freezing of A and C, *o g* that of J and C, *e g* the reaction line whereby the B-rich solid solution forms at the expense of the C-rich one. *L o* is the reaction line for the formation of the compound J and *g f* the simultaneous freezing of the compound J and the B-rich solid solution.

Case V.—The metals A and B, and B and C, form eutectics as in Curve II, Fig. 2. A and C form a compound, and a reaction occurs between this compound and the liquid to form a solid solution rich in C—there being no eutectic, as in Curve VII, Fig. 2.

This is shown in Fig. 9, which represents the lead-tin-antimony series and will be discussed later.

THE LEAD-TIN-ANTIMONY SERIES.

The ternary alloys of lead, tin and antimony find considerable application in the arts as bearing-metal, type-metal, white-metal for small castings, etc.

In regard to the composition of alloys used in practice the list given in Table I embraces the most important. A few alloys containing a small amount of copper are also given for comparison, Table II. Looking down the list we see that the antimony never exceeds 30 per cent. The lead varies from 93 down to 5 per cent and the tin from 1 up to 75 per cent. There is no uniform variation, however.

The physical properties of this series of alloys are not very well known; at least, they have not been published in detail, and while the anti-frictional qualities within certain limits of use do not show the wide differences one would expect from the variation in composition, there is probably a fairly marked difference in crushing strength as we pass from the lead-rich to the tin-rich side, judging from the structure.

Charpy[1] in a study of white alloys called anti-friction, examined some alloys of the lead-tin-antimony group in regard to their crushing strength and microstructure.

Before taking up the ternary alloys a few notes on the binary alloys will be given.

Lead-Antimony.—Antimony freezes at 631° C., lead at

[1] *Metallographist*, Vol. II, p. 9 (1899).

TABLE I.—COMPOSITION OF LEAD-TIN-ANTIMONY ALLOYS.

No.	Name of Metal.	Percentage of				Authority.
		Lead.	Tin.	Antimony.	Other Metals.	
1	Electrotype	93.0	3.0	4.0		
2	Bearing	86.0	1.0	13.0		
3	Linotype	85.0	3.0	12.0		
4	Bearing	83.3	8.3	8.3		
5	English Linotype	83.0	5.0	12.0	.....	Kaiser.
6	English Stereotype	82.5	4.5	13.0	.....	Kaiser.
7	Stereotype	82.0	6.0	12.0		
8	Bearing	82.0	2.0	16.0		
9	Stereotype	82.0	3.2	14.8	.....	Roberts-Austen.
10	Bearing	80.0	10.0	10.0		
11	Bearing, Compagnie del'Est	80.0	12.0	8.0	.....	Charpy, Guillet.
12	Bearing	80.0	5.0	15.0	.....	Guillemin, Guillet.
13	Bearing, like "Glyco," etc.	80.5	4.5	14.5	As 0.5	
14	Bearing, like "Magnolia"	78.0	6.0	16.0		
15	Bearing, Magnolia and Tandem	77.7	5.9	16.8	.....	Law, Thurston.
16	Type	77.5	6.5	16.0		
17	Stereotype	76.0	4.0	20.0	.....	Kaiser.
18	Bearing	76.0	7.0	17.0		
19	Metallic packing, Compagnie d'Orleans	76.0	14.0	10.0	.....	Guillet.
20	French Auto	75.0	10.0	15.0	.....	Kaiser.
21	Type, German	75.0	2.0	23.0	.....	Kaiser.
22	Bearing, American R. R. (also English Monotype)	73.5	8.0	18.5		
23	Piston Packing, Compagnie de Nord	73.0	12.0	15.0	.....	Guillet.
24	Bearing, French R. R.	70.0	20.0	10.0	.....	Charpy.
25	Stereotype, Mackenzie	70.0	13.0	17.0	.....	Thurston.
26	Bearing, Paris-Lyon-Mediterranee R. R.	70.0	10.0	20.0	.....	Guillet.
27	Stereotype	70.0	7.0	23.0	.....	Kaiser.
28	Bearing, American R. R.	68.0	21.0	11.0		
29	Bearing, Graphite	68.0	15.0	17.0	.....	Dudley, Guillet.
30	Stereotype	67.0	17.0	18.0	.....	Thurston.
31	Locomotive bushing	65.6	18.8	15.4	.....	Kaiser.
32	Bearing	62.0	27.0	10.0		
33	Type	60.0	35.0	5.0		
34	Type, German	60.0	34.6	5.4	.....	Kaiser.
35	Bearing	60.0	20.0	20.0	.....	Brannt.
36	Type, German	60.0	15.0	25.0	.....	Kaiser.
37	Type, common	60.0	10.0	30.0	.....	Law.
38	Solder	60.0	39.0	1.0		
39	Type	55.5	40.0	4.5		
40	Type, best	50.0	25.0	25.0	.....	Law.
41	Type, French	55.0	22.0	23.0	.....	Kaiser.
42	Type, French	55.0	15.0	30.0	.....	Kaiser.
43	Hoyle's metal	42.0	46.0	12.0	.....	Hiorns, Guillet.
44	Bearing, Chemin de fer del'Est Français	42.0	42.0	16.0	.....	Guillet.
45	Bearing	40.0	45.0	15.0	.....	Ledebur, Guillet.
46	Bearing, Italian R. R.	37.0	38.0	25.0	.....	Thurston, Guillet.
47	Stereotype	35.0	60.0	5.0	.....	Berthier, Thurston.
48	Bearing	10.0	75.0	15.0		
49	For small castings	5.0	75.0	20.0		

327° C. The addition of lead to antimony, or of antimony to lead, lowers the freezing point. The freezing-point diagram, showing the relation of percentage composition to temperature of freezing, was worked out by Roland-Gosselin,[1] who found that

[1] Gautier, Bulletin de la Société d'Encouragement, Fifth Series, Vol. I, 1896, p. 1293.

the eutectic or alloy with the lowest freezing point contained 13 per cent antimony and froze at 228° C.

Stead,[1] in a paper on the microchemical examination of lead-antimony alloys, showed the eutectic contained 12.8 per cent antimony and froze at 247° C. Gontermann[2] gave 13 per cent and 245° C.

The freezing-point, or thermal diagram, is shown in Fig. 7. Temperatures are represented in the vertical scale and per-

TABLE II.—COMPOSITION OF LEAD-TIN-ANTIMONY-COPPER ALLOYS.

No.	Name of Metal.	Percentage of					Authority.
		Lead.	Tin.	Anti-mony.	Copper.	Other Metals.	
1	Bearing	80.5	11.6	7.4	0.5		
2	Hard lead	80.0	7.5	12.0	0.5	.....	Kaiser.
3	Bearing (Katzenstein)	77.6	7.3	16.8	0.4	.....	Kaiser.
4	Anti-friction	77.0	10.0	12.5	0.5		
5	Anti-friction	77.0	8.0	14.0	1.0		
6	White	77.0	5.0	15.0	2.3		
7	Bearing, A	73.0	8.5	18.0	0.4		
8	Bearing, B	68.0	9.6	20.5	1.6		
9	Bearing, C	71.0	7.7	18.5	2.0		
10	Type	70.0	10.0	18.0	2.0	.....	Roberts-Austen.
11	Type, English, Old	69.2	9.1	19.5	1.7	.....	Kaiser.
12	Type	63.2	12.0	24.0	0.8		
13	Bearing	62.5	26.2	10.0	1.3		
14	Bearing	61.0	25.0	13.0	1.0		
15	Type	60.5	14.5	24.2	0.8		
16	Type, Krupp	59.6	12.0	18.0	4.7	Ni 4.7 Bi 1.0	Kaiser.
17	Type, English	58.0	15.0	26.0	1.0	.....	Kaiser.
18	Bearing	48.0	40.0	10.0	2.0		
19	Bearing, American	46.0	36.5	16.5	1.0		
20	Bearing, German	40.0	42.0	16.0	2.0		
21	Bearing	37.0	50.0	12.0	1.0		
22	White	33.0	53.0	10.6	2.4	Zn 1.0	Roberts-Austen.
23	White	33.9	49.1	13.6	3.3	.....	Kaiser.
24	Bearing	25.5	61.0	10.5	2.8		
25	Pewter	11.5	87.2	5.7	1.6	.....	Kaiser.
26	Bearing	11.8	74.0	9.5	4.7		
27	Bearing	10.0	75.0	12.0	3.0		

centage composition in the horizontal, as before. *A*, or 631° C., shows the freezing point of antimony, which is lowered along the curve *Ar* as the proportion of lead in the alloy increases. Similarly *B*, or 327° C., is the freezing point of lead which is depressed along the curve *Br* as the antimony in the alloy increases. These two curves, indicating the freezing out of

[1] *Journal*, Society of Chemical Industry, March and June, 1897. *Metallographist*, Vol. I, p. 179 (1898).

[2] *Zeitschrift für anorganische Chemie*, Vol. 55, p. 419 (1907).

the antimony and the lead respectively, intersect at the point *r* or 13 per cent antimony at 247° C., the eutectic alloy, which is composed of a mechanical mixture of lead and antimony due to their simultaneous freezing.

Thus alloys containing 100 to 13 per cent antimony are composed of crystals of antimony in an increasing amount of the eutectic or ground mass; a type of structure which is shown in Figs. 12, 13 and 14. At 13 per cent antimony the alloy is all eutectic and may be represented by Fig. 15. Alloys from zero to 13 per cent antimony are composed of crystals of lead in dendritic form set in an increasing amount of the eutectic. Fig. 18 represents this type.

In short, above the curve *ArB* the alloys are completely liquid, below the horizontal line at 247° C. everything is solid.

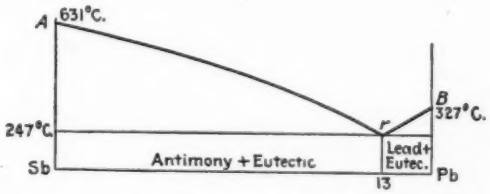


FIG. 7.—The Lead-Antimony Thermal Diagram.

In the left triangle, we have crystals of antimony in a liquid alloy; in the right triangle crystals of lead in a liquid.

Lead-antimony alloys are used as bearing-metal, type-metal, hard lead, etc.

Lead-Tin.—The curve for lead and tin is similar to that of lead and antimony. As determined by Kupffer,[1] the eutectic contains 37 per cent lead and freezes at 182° C. Charpy[2] gives 38 per cent lead, 62 per cent tin. Roberts-Austen[3] gave the point at 68 per cent tin and 180° C. and published curves showing tensile strength and extensibility. Tucker and Rosenhain[4] found the exact point to be 63 per cent tin, freezing at 182°.5 C.

[1] *Annales de Chimie et de Physique*, 2d Series, Vol. XL, p. 289.
[2] *Metallographist*, Vol. II, p. 9 (1899).
[3] Fourth Report, Alloys Research Committee, Inst. Mech. Engrs., Feb., 1897.
[4] *Philosophical Transactions*, Royal Society, Vol. 209 A, p. 89 (1909).

Thus alloys with less than 63 per cent tin are composed of crystals of lead set in the eutectic; those with more than 63 per cent tin are composed of crystals of tin set in the eutectic. Solid lead holds some tin in solution, the amount varying with the rate of freezing. Rosenhain and Tucker were able to get 16 per cent in solution by long annealing. As ordinarily made, however, the amount is very much less. Changes in the solid also occur.

The lead-tin alloys are used as solders and pewter, in the manufacture of toys, etc.

Tin-Antimony.—From a microscopic study of alloys of antimony and tin Charpy[1] found a definite compound containing about 50 per cent antimony which forms isomorphous mixtures with antimony. He found (incorrectly) a eutectic at about 10 per cent antimony.

Stead[2] showed that up to 7.5 per cent antimony the alloys consist of a solid solution, above this point cubes of a compound SbSn separate out when the alloy freezes. At the antimony end of the series crystals of antimony are the first to form.

The constitution of these alloys was not understood until Reinders[3] published his thermal diagram. Later Gallagher[4] modified the curve and showed a thermal transformation in the cubes (SbSn of Stead) at about 315° C.

Williams[5] gave a simpler curve and omitted the transformation at 315° C. The main points of these three curves are the same however, and Fig. 8 is taken from them, somewhat simplified, to explain the main changes, which were discussed under Curve VII, Fig. 2.

The addition of tin to antimony lowers the freezing point progressively. The curve, Fig. 8, shows two inflections at *f* and *d* with two horizontals *f g h* and *d e* g_1. There is no true eutectic, as pure tin freezes lower than any of the alloys of the series. Such a curve shows that above *A f d C* all is liquid; below *A h g* g_1 *e C* all is solid. Between these two curves we have a mixture of solid and liquid. It also shows that at 422° C.,

[1] *Metallographist*, Vol. I, p. 197 (1898).
[2] *Journal*, Soc. of Chem. Ind., Dec. 31, 1898. *Metallographist*, Vol. II, p. 314 (1899).
[3] *Zeitschrift für anorganische Chemie*, Vol. 25, p. 113 (1909).
[4] *Journal of Physical Chemistry*, Vol. X, p. 93 (1906).
[5] *Zeitschrift für anorganische Chemie*, Vol. 35, p. 12 (1907).

the alloys from 90 to 50 per cent antimony show a reaction whereby the solid corresponding to *h* reacts with the liquid corresponding to *f* to form solid *g*. Now *h* is antimony containing 10 per cent tin in solid solution, Sbβ for short; *g* corresponds to SbSn. The liquid *f* contains about 50 per cent antimony. Similarly at 244° C. we have the reaction of *g* or SbSn with the liquid *d* (8 per cent antimony) to form the solid *e* containing 10 per cent (a solid solution of tin with 10 per cent of antimony, or Snα for short). Then from 100 to 90 per cent antimony we have Sbβ. From 90 to 52 per cent antimony we have Sbβ surrounded by a ground mass of SbSn. From 52 to 10 per cent antimony we have SbSn in a ground mass of Snα (Fig. 21) while from 10 to 0 per cent antimony we have Snα, tin containing antimony in solid solution.[1]

For the sake of simplicity we have omitted the change in

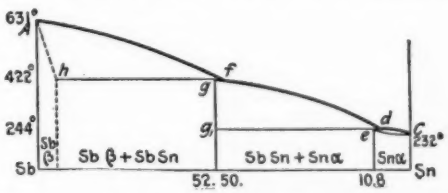


FIG. 8.—The Tin-Antimony Thermal Diagram.

the SbSn at 315° C. and also the fact that SbSn probably is capable of holding some 2 per cent of tin in solid solution. In addition, while antimony dissolves 10 per cent tin at 422° C., the amount at ordinary temperatures is much less.

Tin-antimony alloys have been used as the basis of britannia metal, for anti-friction alloys, for processes of engraving, etc.

Lead-Tin-Antimony.—The ternary diagram has been worked out by R. Loebe[2] and by Campbell and Elder.[3, 4] It is Case V above, namely where A B and B C form eutectics and have curves represented by Fig. 7, or Curve II, Fig. 2, while the pair A C shows no eutectic as in Curve VII, Fig. 2, or Fig. 8.

[1] Type photographs, Campbell. *Journal*, Amer. Chem. Soc., Vol. VI, p. 1308 (1904).
[2] *Metallurgie*, Vol. VIII, p. 7 (1911).
[3] *School of Mines Quarterly*, Vol. XXXII, p. 244.
[4] *Metallurgie*, Vol. IX, p. 422 (1912).

Fig. 9 gives such a ternary diagram and the following is a brief description of the changes that take place when an alloy solidifies. *A* represents antimony, *B* is lead and *C* is tin. Then *r* is the eutectic of lead and antimony with 13 per cent antimony, freezing at 247° C.; *q* is the eutectic of lead and tin with 63 per cent of tin, freezing at 182° C. On the side *AC* the point *g* represents SbSn, *f* the reaction point at 422° (*f* in Fig. 8), *d* the reaction point at 244° (*d* in Fig. 8), and *e* is 10 per cent antimony, or saturated Snα.

In the area *ArOf* the first solid to form is antimony (with a little tin in solid solution). In the area *BrOPq*, lead crystallizes out first. In *fOPd*, SbSn forms first, while in

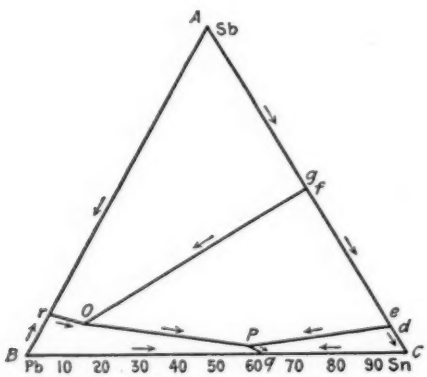


FIG. 9.—The Lead-Tin-Antimony Diagram.

CdPq, tin crystallizes out first with more or less antimony in solid solution (Snα).

Assuming for the sake of simplicity that pure antimony crystallizes out, in the triangle *AOr* an alloy will deposit crystals of antimony on freezing until the composition of the liquid reaches a point on the line *rO*. Then we shall have lead and antimony freezing out side by side and the liquid composition sliding down the line *rO* till it reaches the reaction point *O*. At this point we have the reaction antimony crystals plus liquid *O* forming solid SbSn+Pb. If the liquid is used before the antimony the alloy becomes solid at *O*. If not, when the antimony has disappeared the liquid follows the line *OP* and

we have SbSn and Pb separating out side by side till the alloy finally is all solid.

In the area *BOr* the first to freeze are crystals of lead and the liquid reaches the line *rO*, the further changes being as above.

In the area *AOf*, antimony crystals freeze out and the liquid reaches the line *fO* and follows down it toward *O*. This change in composition of the liquid is brought about through a reaction between the solid antimony and the liquid to form SbSn. On reaching *O* as before we have the reaction above mentioned, but if the antimony is all gone before the liquid reaches *O*, further solidification occurs as in the next case.

In the area *fPO*, SbSn crystallizes and the liquid reaches the line *OP* and follows it due to the simultaneous freezing of SbSn and Pb. On reaching the point *P* we have another reaction similar to the one at *O*. Here SbSn plus liquid P react to form solid Snα+Pb. As before, if all of the SbSn is used before the liquid P, further freezing follows the line *Pq* and the alloy finally goes solid.

In the area *BOP*, lead freezes out first and the liquid on reaching line *OP* follows it as above.

In the area *BPq*, lead crystallizes out first and on the liquid reaching the line *Pq*, lead and tin (Snα) freeze out side by side till *q*, the binary eutectic of lead and tin, also the eutectic of the system, is reached.

In the area *fPd* crystals of SbSn are the first to form. When the liquid reaches the line *dP* this stops and we get the reaction SbSn+liquid=Snα, which continues as the liquid follows the curve *dP* to *P*. If the liquid uses all of the SbSn before *P* is reached, further freezing takes place as in the next case. If not, then at *P* we get the reaction SbSn+liquid P =Snα+Pb, and the alloy finally becomes solid.

In the area *CdPq* we have the tin solid solution (Snα) first freezing out and the liquid reaches the line *Pq* as before.

In short, the line *rO*, the boundary between the antimony area and the lead area, represents the simultaneous freezing of lead and antimony. The line *OP* is the boundary between the lead and the antimony-tin areas and represents the simultaneous freezing of Pb and SbSn, while *Pq* is the boundary

between lead and tin and represents the simultaneous freezing of these two. All of these give structures resembling that of a true eutectic.

On the other hand the boundary line *fO* represents the reaction whereby SbSn forms at the expense of the antimony and *dP* represents the reaction whereby Snα forms at the expense of SbSn. The two points are:

(1) *O* at 80 per cent lead, 10 per cent tin, and 10 per cent antimony at 245° C.
(2) *P* at 40 per cent lead, 57.5 per cent tin, and 2.5 per cent antimony at 189° C.

Microstructure.—In the preparation of sections for the microscope the pieces must be sawed through vertically because there is often a marked difference between the top and the bottom of the specimen. This is due to the fact that both the antimony and the SbSn crystals are much lighter than the liquid out of which they freeze, and they therefore tend to float to the surface of the melt. After cutting with a saw, the surface of the section must be carefully filed to take off all of the surface altered in the process of cutting. If this is not done, the structure will be broken up and obscure. After polishing in the usual way, the final polish on a rouge board must be continued longer than usual until a good surface is obtained. As an etching reagent, two-per-cent nitric acid in alcohol is very good.

With small melts cooled in the air the structure shows that equilibrium is not always established. Alloys in that part of the area *ArOf*, Fig. 9, whose antimony ought all to have disappeared due to the reaction on *fO* or at *O*, often show undissolved cores of antimony. Similarly with SbSn in the area *fOPd*. With very slow cooling, of course, conditions would have brought about more complete equilibrium.

The microstructure of the series is typically shown in the following photographs, magnified 45 diameters.

Fig. 12.—Pb 83, Sn 2, Sb 15.—An alloy from the area *AOr*, Fig. 9. The white crystals are antimony surrounded by the binary Pb and Sb which froze along *rO*. The ground mass is a mixture of Pb and SbSn which froze by reaction of the solid

antimony and the liquid at *O*. Owing to the comparatively rapid rate of cooling, equilibrium was not reached at *O* and freezing continued along *OP* as shown by the cooling curve of this alloy.

Fig. 13.—Pb 75, Sn 10, Sb 15.—The white crystals are antimony surrounded by the ground mass of Pb and SbSn which froze at *O* and along *OP* as above. The view is from the top of the alloy and is comparatively rich in Sb because the crystals, being lighter than the liquid out of which they froze, rise towards the surface.

Fig. 14 represents an alloy from the area *gOP* near *O*, Fig. 9. The white cubes are SbSn, surrounded by the binary Pb-SbSn. The view is from the top of melt.

Fig. 15 shows another part of the same alloy composed almost entirely of the binary Pb-SbSn, showing its characteristic skeleton structure.

Fig. 16.—Pb 60, Sn 25, Sb 15.—White crystals of SbSn surrounded by a half-tone envelope of the binary Pb-SbSn which froze along *OP*, while the dark ground mass froze at the point *P* by reaction, whereby SbSn plus liquid P formed Snα+Pb.

Fig. 17.—Pb 67, Sn 25, Sb 8.—An alloy on the line *OP*, Fig. 9. The white masses are the binary Pb-SbSn, surrounded by the dark ground mass, which froze by reaction at *P* as before.

Fig. 18.—Pb 85.5, Sn 5, Sb 9.5, Bi 0.5.—This has the structure of alloys in the area *BOr*, Fig. 9. The black dendrites are lead, surrounded by the binary Pb-SbSn which became solid at *O* as in Fig. 13.

Fig. 19.—Pb 37.5, Sn 60, Sb 2.5.—An alloy from the area *CdPq*, Fig. 9. The white dendrites are Snα surrounded by the binary Pb-Snα which froze along *Pq*.

Fig. 20.—Pb 40, Sn 57.5, Sb 2.5.—The alloy P, a mechanical mixture of Pb and Snα which froze along *Pq*.

Fig. 21.—Pb 10, Sn 67.5, Sb 22.5.—An alloy from the area *gPd*, Fig. 9. The white cubes are SbSn set in the lighter Snα. Equilibrium was not reached on account of too rapid cooling and the dark envelopes around the Snα are the beginning of the binary Pb-Snα which freezes along *Pq*.

THE ALLOYS OF TIN, ANTIMONY AND COPPER.

These alloys find extensive use as bearing metal, britannia metal, etc. Table III gives some typical analyses from various sources and shows that the tin usually exceeds 70 per cent, the antimony usually is less than 20 per cent and the copper under 10 per cent. Charpy[1] examined some twenty alloys as regards microstructure and compressive strength. Before discussing the ternary alloys a word or two must be said of the copper-tin series.

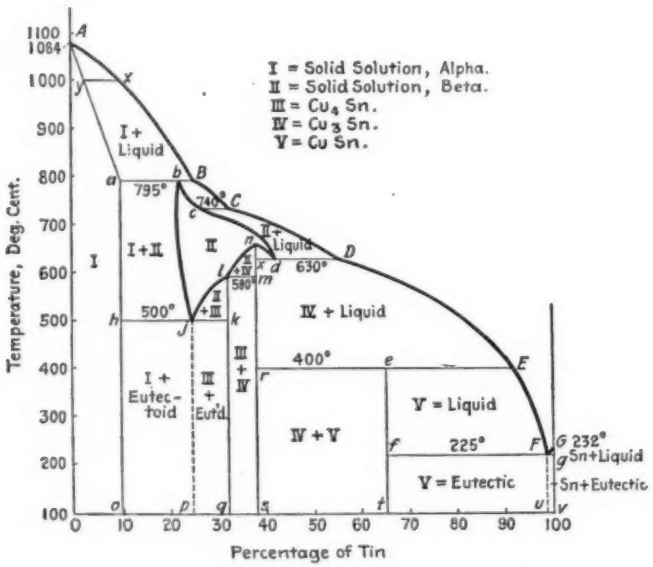


FIG. 10.—The Copper-Tin Thermal Diagram.

Copper-Tin Series.—In Fig. 10 is given a simplified diagram. Some of the changes have been omitted (for example, that which occurs in the alloys between *c* and *C* at 740° C.), because the various researches, notably by Heycock and Neville, Shepherd and Blough,[2] Giolitti and Tavanti,[3] do not agree, and these points are still unsettled. The freezing-point curve or liquidus is *A B C D E F G*. The solidus or end of freezing is given by

[1] *Metallographist*, Vol. II, p. 9 (1899).
[2] *Journal of Physical Chemistry*, Vol. X, p. 630 (1906).
[3] *Gazetta Chimica Italiana*, Vol. 38, II, p. 209 (1908).

TABLE III.—COMPOSITION OF TIN-ANTIMONY-COPPER ALLOYS.

No.	Name of Metal.	Percentage of				Authority.
		Tin.	Anti-mony.	Copper.	Other Metals.	
1	Algiers	94.5	0.5	5.0	.....	Kaiser.
2	English Britannia	94.0	5.0	1.0	.....	Law.
3	Britannia, spinning	93.7	3.75	2.6	.....	Kaiser.
4	Tutania, cast	92.4	4.6	2.5	Pb 0.32 Fe 0.13	Kaiser.
5	English, sheet	91.5	7.1	1.4	.....	Kaiser.
6	Bearing	91.0	4.5	4.5		
7	Bearing, Prussian	91.0	6.0	3.0	.....	Kaiser.
8	English Britannia, sheet	90.6	7.8	1.5	.....	Brannt.
9	English Britannia, cast	90.6	9.2	0.2	.....	Law.
10	Bearing	90.0	6.0	4.0		
11	Bearing, Russian R. R.	90.0	8.0	2.0	.....	Thurston.
12	English Britannia	90.0	6.0	2.0	Bi 2.0	Law.
13	English Britannia, Bearing	90.0	7.0	3.0	.....	Law, Kaiser.
14	Auto Bearing, American	89.0	7.0	4.0	.....	Kaiser.
15	Bearing	89.3	8.9	1.8	.....	Thurston.
16	Pewter	89.3	7.0	1.8	Pb 1.8	Brannt.
17	Pewter	89.3	7.6	1.8	Bi 1.8	Kaiser.
18	Pewter	87.2	5.7	1.6	Pb 11.5	Kaiser.
19	Pewter	84.7	1.7	6.8	Bi 6.8	Kaiser.
20	Bearing	88.9	7.4	3.7	.....	Karmarsch, Bolley.
21	Queen's	88.5	7.1	3.5	Zn 0.9	Law.
22	Queen's	88.5	7.0	3.5	Bi 1.0	Law.
23	Britannia, spoons	88.4	8.7	2.9	.....	Kaiser.
24	Bearing	87.0	7.0	6.0	.....	Hiorns.
25	White, Hanover	86.8	7.6	5.6	.....	Kaiser.
26	English Britannia	85.5	9.7	1.8	Zn 3.0	Law.
27	English, Britannia, cast	85.5	10.5	1.0	Zn 3.0	Kaiser.
28	Britannia, spoons	85.5	14.4	0.15	.....	Kaiser.
29	Britannia, spoons	84.7	5.0	3.7	Bi 4.9 Zn 1.5	Kaiser.
30	Bearing, heavy	85.0	7.5	7.5		
31	Jacoby	85.0	10.0	5.0	.....	Ledebur, Brannt.
32	Argentin	85.0	14.5	0.5	.....	Kaiser.
33	German Britannia	84.0	9.0	2.0	Zn 5.0	Law, Brannt.
34	French car-bearings	83.3	11.1	5.5	.....	Charpy.
35	Bearing	83.3	8.3	8.3		
36	Bearing, German R. R.	83.0	11.0	6.0	.....	Ledebur.
37	Bearing, valve rods, etc	82.0	10.0	8.0	.....	Law.
38	Bearing, French R. R.	82.0	12.0	6.0	.....	Ledebur.
39	Brittania (Baumgartel)	81.9	16.3	1.8	.....	Bolley, Brannt.
40	White, Dutch	81.5	8.8	9.6	.....	Kaiser.
41	Bearing, piston	81.0	12.5	6.5	.....	Kaiser.
42	Bearing, Swiss R. R.	80.0	10.0	10.0	.....	Thurston.
43	Tutania, English	80.0	16.0	2.7	Zn 1.3	Kaiser.
44	Ashberry	80.0	14.0	2.0	Zn 1.0	Law.
45	Ashberry	79.0	15.0	3.0	Zn 2.0	Law.
46	Britannia, Ashberry	77.8	19.4	2.8	.....	Thurston, Bolley.
47	Britannia, Ashberry	77.9	19.4	0.0	Zn 2.8	Roberts-Austen.
48	Bearing, English	76.7	18.5	7.8	.....	Brannt, Bolley.
49	Bearing, German	76.0	17.0	7.0	.....	Brannt.
50	Bearing, Prussian	74.0	15.0	11.0	.....	Kaiser.
51	Husmann	73.6	11.0	4.0	Pb10.6 Zn 0.18 Fe 0.22	Kaiser.
52	Bearing	73.0	18.0	9.0	.....	Thurston.
53	Bearing	72.0	26.0	2.0	.....	Thurston, Bolley.
54	German, Britannia	72.0	24.0	4.0	.....	Brannt. Law.
55	German, Ludenscheidt	71.8	24.3	3.85	.....	Kaiser.
56	Bearing (Kamarsch)	71.4	7.2	21.4	.....	Thurston, Bolley.
57	Bearing, valve packing	71.0	24.0	5.0	.....	Thurston.
58	German	70.8	15.1	4.9	Pb 9.2	Kaiser.
59	Bearing (Kamarsch)	70.7	19.7	9.5	.....	Thurston, Bolley.
60	Minofor (Britannia)	68.5	18.2	3.3	Zn 10.0	Brannt, Law.
61	Bearing, G. W. R. (England)	67.0	11.0	22.0	.....	Thurston.
62	Bearing, French R. R.	67.0	22.0	11.0	.....	Law, Charpy.
63	Minofor	66.0	20.0	4.0	Zn 9.0	Kaiser.
64	Dewrance (locomotive)	33.3	44.5	22.2	.....	Charpy, Hiorns.

A a b c d n r e f F g. In alloys from 0 to 38.2 per cent, tin (Cu_3Sn) the curves below the solidus represent changes in the solid alloy.

If we consider the copper-tin thermal diagram in small parts, it at once becomes simple, being merely compounded of a number of simple curves, already discussed.

Tin-Rich Alloys.—The alloys with more than 38.2 per cent tin are all brittle and of no commercial importance until we get to about 85 per cent tin. This part of the curve shows two horizontals *Dx* and *Eer* besides the eutectic line *fFg*. At 630° C., the line *Ddx* gives the temperature of the reaction solid solution II, equals solid IV, or Cu_3Sn plus liquid D. Similarly the line *Eer* at 400° C. represents the reaction,

$$\text{IV } (Cu_3Sn) + \text{liquid E} = \text{V (CuSn)}.$$

Theoretically this reaction ought to be complete, and in alloys from 38.2 to 65 per cent tin the liquid is all used before the Cu_3Sn, and therefore we get kernels of Cu_3Sn surrounded by a ground mass of hard white CuSn or IV+V. In practice, however, the CuSn forms envelopes around the Cu_3Sn and the reaction is not complete, so in the area IV+V we find Cu_3Sn +CuSn and some eutectic, while in alloys from 65 to 92 per cent tin, *e* to *E*, we find more or less cores of Cu_3Sn inside the CuSn set in the excess eutectic (Fig. 23). Theoretically all of the Cu_3Sn should be used (and is, on very slow cooling) before the liquid, and the resulting alloys should be CuSn (V)+eutectic.

On the right-hand side of the diagram, Fig. 10, we have the V curve *EFG*. This is similar to that of Curve VI, Fig. 2, for *EF* denotes the freezing out of CuSn in laths and needles, *FG* the freezing of crystals of tin in dendrites, while the horizontal *gFf* is the freezing of the eutectic of Sn and CuSn. The CuSn needles, skeleton stars, etc., are quite characteristic and together with the CuSn-Sn eutectic enter into the constitution of tin-rich babbitt metals (Figs. 22 and 26).

The horizontal *Eer* illustrates the case of the compound which dissociates before reaching the melting point; thus on heating, CuSn (V) splits up at 400° C. into Cu_3Sn (IV) plus liquid E.

The eutectic point *F* is one per cent copper and 225° C.

(Fig. 25). In the alloys with less than one per cent copper we have grains and dendrites of tin surrounded by the eutectic (Fig. 24). Thus in the useful alloys we have as follows:

15 to 8 per cent copper, cores of Cu_3Sn, envelopes and needles of CuSn set in the eutectic. (Figs. 23 and 27.)

8 to 1 per cent copper, CuSn needles, stars, etc., in the eutectic. (Figs. 22 and 26.)

1 to 0 per cent copper, dendrites and grains of tin surrounded by the eutectic of tin and CuSn. (Figs. 24 and 25.)

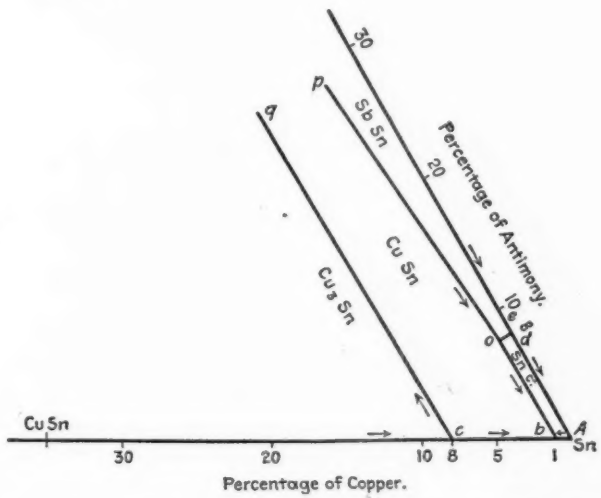


FIG. 11.—Part of Provisional Copper-Antimony-Tin Diagram.

The Ternary Alloys, Tin-Antimony-Copper.—In Fig. 11 is given an approximate diagram up to 30 per cent antimony and 30 per cent copper, worked out from micro-structure. The changes which take place are similar to those of the lead-tin-antimony series.

The line *cq* represents the reaction between Cu_3Sn and the liquid to form CuSn. The line *do* is the reaction between SbSn and the liquid to form Snα. The line *po* is the simultaneous freezing of SbSn and CuSn, while *ob* is the simultaneous freezing of Snα and CuSn, giving a eutectic-like structure as in Fig. 25.

The point *o* is approximately 1 per cent copper, 7.5 per cent antimony, 91.5 per cent tin and represents the reaction,

$$SbSn + \text{liquid } o = Sn\alpha + CuSn.$$

Any alloy on the left of *qc* will freeze out Cu_3Sn and when the liquid reaches the line *cq* we get the reaction to form CuSn. Now in ordinary cooling, the Cu_3Sn is soon covered by CuSn (Figs. 23 and 27) and the reaction stops while CuSn continues to freeze out normally from the liquid. The further structure of the alloy depends on whether the liquid reaches the line *po* or *ob*. Suppose the liquid reaches *po*, then we get a simultaneous separation of CuSn and SbSn following *po* till at *o* we get the reaction to form $Sn\alpha + CuSn$. Again the reaction is not completed and the composition of the liquid follows *ob* till the whole is solid.

This is shown in Fig. 30, Sn 67, Sb 11, Cu 22. The dark cores of the flakelike crystals are Cu_3Sn. The white envelopes and dots are CuSn, the white cubes are SbSn and the ground mass is a mechanical mixture of CuSn and $Sn\alpha$ (see Fig. 25) which froze along *ob*.

The case where the liquid reaches *ob* is simpler, for it freezes along *ob* as before and the alloy shows no cubes of SbSn. Fig. 27, Sn 70, Sb 5, Cu 25, shows the dark cores of Cu_3Sn surrounded by the white envelopes of CuSn, in a ground mass which froze along *ob*.

Coming next to those alloys whose composition falls within *pobcq*, the first thing to freeze out is CuSn, thus enriching the liquid in tin and antimony, until it arrives at *po* or *ob*. The further changes are of two kinds as above. Fig. 28, Sn 72.5, Sb 22.5, Cu 5, started to freeze by separating needles and skeleton crystals of CuSn. The liquid finally reached the line *po* and then we had a simultaneous freezing of cubes of SbSn and needles of CuSn until the point *o* was reached. Then follows reaction and solidification along *ob* as before. Fig. 26, Sn 87, Sb 5, Cu 8, began to freeze out CuSn as before, but the liquid reached the line *ob* and followed along it till solid. Therefore no cubes appear.

Any alloy in the area *pode* first freezes out cubes of SbSn. These are lighter than the liquid out of which they freeze and



FIG. 12.—Pb 83, Sn 2, Sb 15.



FIG. 13.—Pb 75, Sn 10, Sb 15.



FIG. 14.—Type Metal.



FIG. 15.—Type Metal.



FIG. 16.—Pb 60, Sn 25, Sb 15.



FIG. 17.—Pb 67, Sn 25, Sb 8.

MAGNIFICATION, × 45.



FIG. 18.—Pb 85.5, Sn 5, Sb 9.5, Bi 0.5.



FIG. 19.—Pb 37.5, Sn 60, Sb 2.5.



FIG. 20.—Pb 40, Sn 57.5, Sb 2.5.

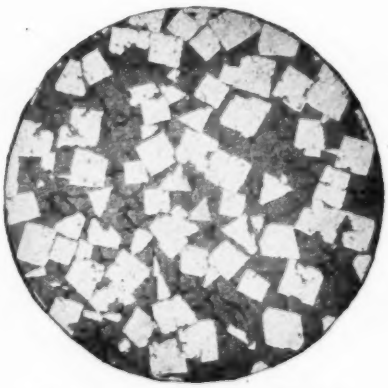


FIG. 21.—Pb 10, Sn 67.5, Sb 22.5.



FIG. 22.—Cu 5, Sn 95.

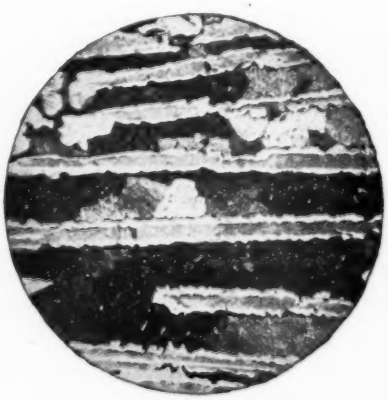


FIG. 23.—Cu 15, Sn 85.

MAGNIFICATION, × 45.



FIG. 24.—Sn 94.5, Sb 5, Cu 0.5.



FIG. 25.—Sn 94, Sb 5, Cu 1.



FIG. 26.—Sn 87, Sb 5, C 18.



FIG. 27.—Sn 70, Sb 5, Cu 25.



FIG. 28.—Sn 72.5, Sb 22.5, Cu 5.

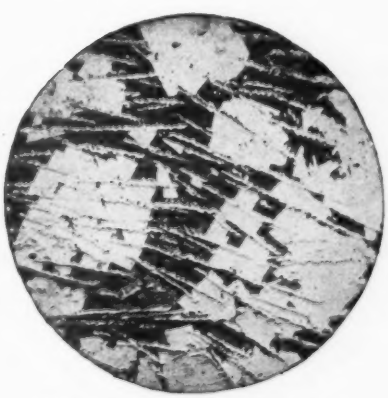


FIG. 29.—Sn 67, Sb 22, Cu 11.

MAGNIFICATION, × 45.



FIG. 30.—Sn 67, Sb 11, Cu 22.



FIG. 31.—Pb 68, Sn 10, Sb 20.4, Cu 1.65.



FIG. 32.—Pb 48, Sn 40, Sb 10, Cu 2.



FIG. 33.—Pb 37, Sn 50, Sb 12, Cu 1.



FIG. 34.—Pb 25.5, Sn 61, Sb 10.5, Cu 2.8.



FIG. 35.—Pb 4, Sn 66, Sb 22.7, Cu 7.3.

MAGNIFICATION, × 45.

float to the surface. The liquid may reach *op* or *od*. If *op*, then SbSn cubes and CuSn needles crystallize out together and freezing continues as already described. If *od*, the cubes tend to react with the liquid to form Snα until *o* is reached. This reaction is never completed in ordinary cooling and further freezing follows *ob* as before.

The reason why the cubes in Fig. 28 have not floated to the surface is because they are held down by a skeleton of CuSn crystals which froze before or with them. This is well shown in Fig. 29.

Alloys on the line *ob* are represented by Fig. 25, Sn 94, Sb 5, Cu 1. Here we see Snα and CuSn separating simultaneously and we get a pseudo-eutectic structure.

Lastly alloys within the area *bodA* consist of dendrites and grains of Snα set in this pseudo-eutectic which freezes along *ob*. Fig. 24 shows the alloy Sn 94.5, Sb 5, Cu 0.5. The dark etching grains are the Snα surrounded by the lighter ground mass, a mixture of Snα and CuSn.

From the above it will be seen that in this series most of the alloys are not in a state of equilibrium because the various reactions are incomplete. As the copper content is increased the amount of CuSn increases till finally we have Cu_3Sn present. This increase in copper increases the hardness and brittleness, and decreases the plasticity proportionately. Similarly an increase in antimony increases the amount of the hard cubes of SbSn with similar results.

THE ALLOYS OF LEAD-TIN-ANTIMONY AND COPPER.

Depending on the composition, these resemble the lead-tin-antimony or the tin-antimony-copper series.

Fig. 31.—Pb 68, Sn 10, Sb 20.4, Cu 1.65.—The long plates are a compound of Sb and Cu which make the alloy somewhat brittle. The white cubes are SbSn set in a ground mass resembling Fig. 14—a mechanical mixture of Pb and SbSn.

Fig. 32.—Pb 48, Sn 40, Sb 10, Cu 2.—Needles, etc., of CuSn; white cubes of SbSn, around which is a ground mass similar to the above.

Fig. 33.—Pb 37, Sn 50, Sb 12, Cu 1.—A few needles, etc., of

CuSn; characteristic white cubes of SbSn. The ground mass is tin-rich, showing a few dendrites of Pb in the Pb-Snα pseudo-eutectic (Fig. 20).

Fig. 34.—Pb 25.5, Sn 61, Sb 10.5, Cu 2.8.—An increase in the CuSn needles and stars; SbSn in white cubic forms. The ground mass resembles a mixture of Snα and the pseudo-eutectic Snα+Pb (Fig. 19).

Fig. 35.—Pb 4, Sn 66, Sb 22.7, Cu 7.3.—The lath-like crystals are CuSn, several of which have undissolved cores of Cu_3Sn (Fig. 23). The white cubes are SbSn as before. The ground mass contains much Snα with CuSn plates in the pseudo-eutectic of Snα+Pb.

SUMMARY OF STRUCTURES.

In the above alloys we find crystals and dendrites of Sb, SbSn, Cu_3Sn, CuSn, Pb and Snα set in a more or less plastic ground mass which may be composed of Pb-SbSn, Pb-Snα or CuSn-Snα.

The crystals and dendrites and the ground mass vary in hardness and plasticity and so by varying the combinations and the amounts of each we can vary the structure, and therefore the physical properties at will.

Again, due to the fact that both Sb and SbSn are lighter than the liquids out of which they freeze, they tend to float to the surface, and unless they are anchored down by earlier crystals and network of CuSn, etc., or the cooling is extremely rapid, as in thin chill molds, we are bound to obtain very marked segregation, which makes accurate sampling of solid ingots an impossibility. In fact, to obtain an accurate sample we must resort to granulation of the liquid alloy.

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The early work in metallography began with the determination of the freezing-point curves, and is given in the researches of Le Chatelier, Gautier, Roberts-Austen, and others. Later the work of the physical chemists, Tammann, Rooseboom, Bancroft, and their students, showed us the complete thermal diagram and its meaning. Then the classical work of Heycock and Neville on the CuSn diagram, and of Shepherd on the CuZn alloys, showed clearly what metallography could accom-

plish in complex series. The chief references in the text are also given under the bibliography for the sake of convenience.

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DISCUSSION.

Mr. Clamer. MR. G. H. CLAMER.—Mr. Campbell's microphotographs, showing the floating of the tin-antimony crystals to the top, is a very instructive one, and explains in a very satisfactory manner the difficulties which manufacturers of white metal alloys are continually confronted with, namely, the discrepancies in analyses which are reported by various chemists by not taking the samples correctly. Our Sub-Committee on White Metals of Committee B-2 is quite familiar with the difficulties involved, and at a meeting in New York about a year and a half ago, at which we outlined the work to be undertaken, we formulated a method of taking samples as follows: To pour the samples into a bar about 1 in. thick and 6 in. long, then to saw completely through the bar at right angles, 1 in. in from the ends and through the middle, then to mix the sawings and make the analysis from the samples of the mixed sawings. Some five or six samples were so taken and analyses made by different members of the sub-committee. They all agreed fairly well with the exception of the analysis of one of the members who had taken the samples by drilling. This showed conclusively that even though the sample is taken completely through the bar, the sample is not sufficiently finely divided to become properly mixed after taking the sample. Our analyses, however, on the whole, were not sufficiently satisfactory, and our sub-committee asked for the cooperation of the Bureau of Standards to prepare new samples and new methods of sampling and to take up the work of devising a standard method of analysis. I am happy to say that the Bureau expects to be in position to undertake this work, and will probably commence on a new series within a very short time.

The Chairman. VICE-PRESIDENT A. W. GIBBS (*in the chair*).—In this report there is mention of finally settling on three or four standard specifications. Does your committee, by so doing, expect to be able to wipe out some of the endless diversity in formulas for white bearing metals?

MR. WILLIAM CAMPBELL.—That is the object of the committee. At the present time there are widely diversified formulas on the market, and a great many metals that are branded with fancy trade names have very similar compositions. When examined they are found to be merely alloys of tin-antimony-copper, or lead-tin-antimony, with sometimes a little copper. Our committee hopes to formulate a series of five alloys which will properly cover the entire field for which babbitt metal might be used. Our idea is to start with the alloy of highest compressive strength and to arrange the series by decreasing hardness, from the hardest alloy which it is practicable to handle, that is, with satisfactory results, down to the softest lead-antimony alloy. It may be that a series of five will not be sufficient. If so we may have to add a few more, but we hope to arrange a series that will meet the requirements of the engineer. **Mr. Campbell.**

MR. R. S. MACPHERRAN.—Has the structure shown on the slide been developed by etching? If so, what fluid was used? **Mr. MacPherran.**

MR. CAMPBELL.—The material is 2-per-cent nitric acid in water, but on account of the fact that these alloys are so difficult to polish, so soft that the lead will rub over the harder compound SbSn, and that the harder compound will not show the structure as it ought to be, it is often necessary to etch deeply to get rid of the metal which has flowed, then to repolish finely on the rouge and then to re-etch again for photographing. There are lots of tricks in the methods of getting the greatest amount of contrast in the different constituents. Very often, after etching longer than one would think necessary, a rub with a small piece of chamois skin will bring up the cubes and also the crystals of tin, and throw the whole structure out in strong relief. **Mr. Campbell.**

MR. CLAMER.—I should like to ask Mr. Campbell if he has noticed any surface characteristics on the eutectic alloys, that is, metals which have been merely poured and allowed to solidify. **Mr. Clamer.**

MR. CAMPBELL.—Yes, one of the members of the sub-committee sent me some time ago a series of a dozen alloys and I at once recognized the structure of the cast surface. You could separate them quite easily, with the exception of those alloys which lie near the solder group, those containing a great deal of tin and lead and only a small amount of antimony. Apparently, the surface of those alloys was all the same, but **Mr. Campbell.**

Mr. Campbell. for the others, with the lead-rich and tin-rich, the surface structures were very characteristic.

Mr. Clamer. MR. CLAMER.—It has been my experience that, as you approach the eutectic, the top surface of ingots of the lead-antimony eutectic assumes a sort of a wavy structure, whereas, the lower eutectic described by Mr. Campbell, 80 per cent of lead, 10 per cent of tin, and 10 per cent of antimony, exhibits a very bright surface in pouring into little pieces in the form of a button. Quite a number of years ago, before I knew very much about eutectics, we had a customer who had in his employ an Italian who had been imported to mix an alloy for them for making bright pewter toys, buckles, and materials of that kind, these castings being made in iron molds. This Italian was getting quite a salary or royalty for making this alloy, and they sent some of it to us to analyze. We found it was practically the lower eutectic alloy described by Mr. Campbell, but even after getting the analysis, we had to work our way, so to speak, a little above and below the 10 per cent. My recollection is that the tin was somewhat below 10 per cent and the antimony somewhat above 10 per cent. As soon as we got the proper alloy, the surface was very bright and brilliant on top, but just as soon as we were a little bit on one side or the other, the surface became frosty, due to the crystallization of the antimony alloy constituents.

Mr. Karr. MR. C. P. KARR.—I should like to ask what method was used in pouring, whether there was any spout on the ladle, so that the alloy would be sucked in when poured.

Mr. Campbell. MR. CAMPBELL.—The alloys were made in small crucibles holding 50 to 100 grams and melted under potassium cyanide to prevent oxidation.

Mr. Karr. MR. KARR.—Mr. J. L. Jones, of the Westinghouse Electric and Manufacturing Co., made some experiments some years ago, published in *The Metal Industry*, with reference to pouring these alloys with a ladle, in which he dipped the metal out of a pot. He had a little metal shield over the mouth of the pot, which kept back all the scum and he thus poured a clear stream of metal right into the mold, and in that way obtained an ingot free from oxide.

Mr. Campbell. MR. CAMPBELL.—All my alloys have been in small melts, made in crucibles, and slowly cooled.

STRENGTH OF CAST ZINC OR SPELTER.

By Gilbert Rigg and G. M. Williams.

Introduction.

The purpose of the present paper is to show the relative strength of various brands of "spelter" or "cast zinc," when the tests are carried out under the same conditions. The term "spelter" covers a variety of what are really alloys of zinc with small amounts of iron, lead, cadmium, etc. That variations in the amount of these impurities would cause differences in the strength of the resulting alloys, seemed probable from a study of the microstructure of the metal.

Previously published results of tests of the strength of zinc have shown wide variations. Thus the tensile strength, as given by different investigators varies from 2500 to 8000 lb. per sq. in.[1] The compressive strength, of course, will vary with the degree of flattening, for a 10 per cent reduction in length the figures vary from 20,000 to 40,000 lb. per sq. in.[2] The only figures we have been able to find for the modulus of rupture in transverse tests give about 7550 lb. per sq. in. (Thurston, and Hunt & Andrews).[3]

A very great objection to these results is the lack of any published analyses of the material used. Most of the investigators have been content to describe their material simply as "cast zinc." Thurston states that "all the zinc thus tested by the author was very pure, and made from New Jersey calamine." On the other hand, another published test on the compression of "cast zinc," shows a very extraordinary metal, containing 1.28 per cent of copper, 0.89 per cent of tin, and 0.51 per cent of

[1] Hunt & Andrews (Burr, "The Elasticity and Resistance of the Materials of Engineering") give 2522 lb. per sq. in. Roberts-Austen gives 7000 to 8000 lb. per sq. in. Thurston & Stoney give intermediate figures 3000 to 6500 lb. per sq. in.

[2] Thurston (Materials of Engineering—Part III) gives 22,000 lb. per sq. in. He mentions 40,000 as given by other authorities but does not name them.

[3] Thurston (*ibid.*) gives 7540 lb. per sq. in. Hunt & Andrews (quoted by Burr) give 7556 lb. per sq. in.

iron. As has been pointed out above, zinc is a metal whose properties are very largely influenced by the presence of small amounts of impurity and the metal referred to above could scarcely be sold in the market under the title of spelter or zinc.

In addition, it seems desirable to know exactly the relative strengths of various kinds of spelter, when the tests are carried out under the same and standard conditions. As is the case with all cast metals, the physical characteristics of zinc will vary widely with the method of preparing the test specimens. The size of the crystals, their mode of growth, etc., will have a great influence on the strength of the material. An attempt has been made in this work to prepare all the test specimens in the same manner, and to carry out all the tests under exactly the same conditions. In addition a careful analysis has been made of each type of spelter. The results therefore should show the relative strength of the various spelters tested.

In order that the effect of the common impurities on the physical characteristics of the resulting metal may be better understood, the subject of the microstructure of spelter will now be briefly taken up.

THE METALLOGRAPHY OF SPELTER.

Pure zinc consists of crystal grains, more or less polygonal in character, their size and direction of growth depending on the conditions under which their formation takes place. Thus, slow cooling will tend to the formation of large crystals, while rapid cooling will tend to make the crystals very small in size. The crystals will further tend to grow at right angles to the cooling surface. These coarse crystal grains may be seen by the naked eye on the broken surfaces of slabs, or in polished specimens which have been etched with dilute acids.

The crystal grains when examined under the microscope exhibit a difference in color, some appearing dark, other less dark and others bright. (Fig. 1.) This appearance is due to the difference in the orientation of the fine crystals, or crystallites, making up the larger crystal grains. In one grain, the crystallites will be so arranged that nearly all the light falling

[1] J. C. Trautwine, Jr., *Proceedings*, Am. Soc. Test. Mats., Vol. XI, p. 511 (1911).

on them from the vertical illuminator will be reflected to the eye of the observer, and the grain will therefore appear bright. In another, the facets of the crystallites will be so placed that nearly all the light falling on them will be reflected away, and the grain therefore will be dark.

Under higher powers of the microscope and by etching somewhat more deeply, the outlines of some of the crystallites composing the crystal grains may be seen. Fig. 2 represents a specimen of High Grade spelter magnified 233 diameters. The outlines of the crystallites can easily be made out. Fig. 3 shows the cooling curve of pure zinc as given by Arnemann.[1] It shows a single horizontal at 419° C. Attempts to locate other



FIG. 1. ×42.

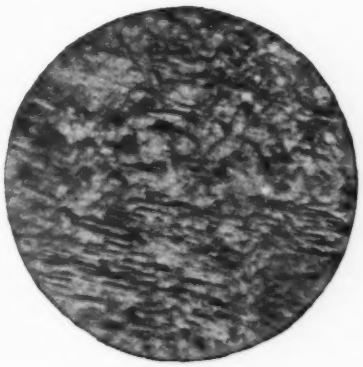


FIG. 2. ×233.

horizontals, corresponding to the supposed allotropic modifications of the solid metal, by thermal methods, were fruitless.

Iron and Zinc.—Iron occurs in spelter as individual, well marked crystals of iron-zinc alloy. These crystals most probably consist of the compound $FeZn_7$ holding with it zinc in solid solution. The diagram of thermal equilibrium for the system iron-zinc as given by Arnemann[2] is shown in Fig. 4. In this the solid lines represent Arnemann's results, the dotted curve shows Vegesack's[3] determinations. At a temperature of 662° C., $FeZn_3$ reacts with the still liquid portion of the melt, forming

[1] P. T. Arnemann, *Metallurgie*, Vol. 7, p. 204 (1910).
[2] Arnemann, *ibid.*
[3] A. von Vegesack, *Zeitschrift für anorganische Chemie*, Vol. 52, p. 30 (1907).

solid solutions of Fe Zn_7 and zinc, whose composition as the temperature falls varies from *o* to *n*. (See Fig. 4.)

Vegesack's conclusions regarding the formation at a temperature of 422° C. of solid solutions of iron in zinc, containing up to 0.7 per cent of iron, were not borne out by Arnemann's work. If these solid solutions were formed, iron-zinc alloys containing from 0 to 0.7 per cent of iron would be homogeneous. We have observed iron alloy crystals as a definite constituent in zinc at percentages as low as 0.03 per cent and must therefore conclude that no such solid solutions are formed. We therefore have the following composition for alloys of iron and zinc:

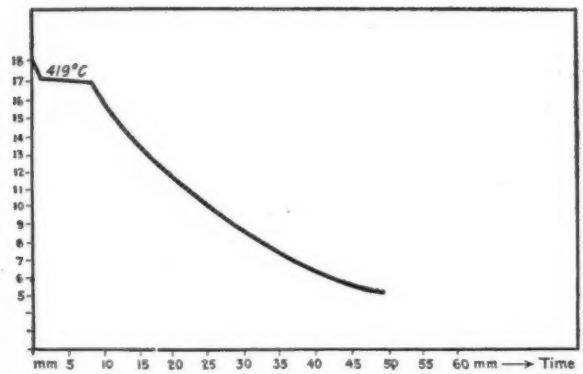


FIG. 3.—Pure Zinc (Mylius and Fromm) Cooling Curve for Investigation of Transformation Points; Slow Cooling (Arnemann).

0.0–7.3 per cent Fe—Two structural elements, (1) Solid solutions or "mixed crystals" of Fe Zn_7 and zinc, containing as a minimum 7.3 per cent iron, (2) Pure Zinc.

7.3–11 per cent Fe—Homogeneous alloys (one structural element) consisting entirely of the solid solution of Fe Zn_7 and Zn.

11–22 per cent Fe—Two structural elements, (1) Fe Zn_3, (2) Fe Zn_7.

By reference to the diagram, it will be noted that the area *CDPV* comprises the limits of concentration and temperature in which Fe Zn_3 is normally present. The lower limit of concentration of Fe Zn_3 is therefore given by the point *C* correspond-

ing to about 4 per cent of iron. As spelter never contains so high an iron content as this, it is evident that $Fe\ Zn_3$ can never be present as a constituent of spelter.

In the case of "dross," however, containing from 4 to 5 per cent of iron, it might be possible, by quenching from above

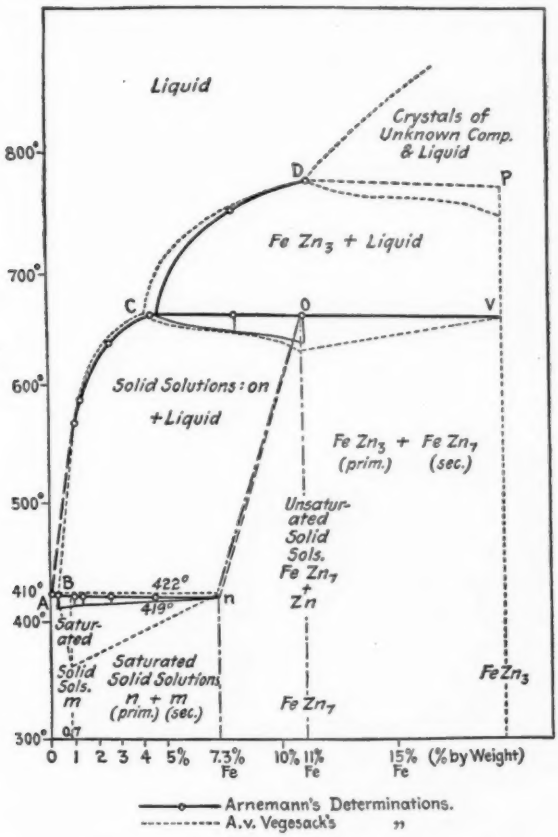


FIG. 4.—Iron-Zinc Diagram (Arnemann).

the temperature represented by the line *COV*, to have $Fe\ Zn_3$ present in the solid alloy.

This "dross," taken from the bottom of the galvanizing pot, well illustrates the appearance of the iron-zinc alloy. The alloy crystals are harder than the ground mass and in addition are

attacked but little by the etching reagent, appearing brilliant and white (Figs. 5 and 6).

Fig. 7 shows an iron-zinc alloy prepared in the crucible and containing 0.51 per cent iron. The crystals are well marked.

Fig. 8 shows a Brass Special spelter which has been poured



FIG. 5. ×40.



FIG. 6. ×51.

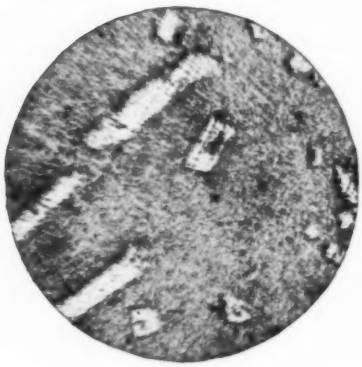


FIG. 7. ×89.

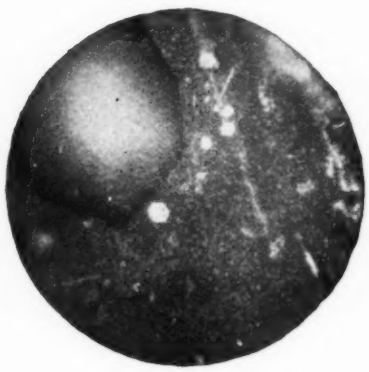


FIG. 8. ×155.

on mica, in order to give a smooth surface for microscopic observation without polishing. The hexagonal character of the iron alloy crystals should be noted.

Fig. 9 shows a spelter containing 0.035 per cent of iron. The alloy crystals, although widely scattered, are still well marked. It may be noted that the concentration of these crystals would

seem to imply an iron content of higher than 0.035 per cent, but it should be remembered that in photographing, one will naturally select an area in which the crystals are concentrated.

As these iron alloy crystals are hard and brittle, their presence in the spelter would tend to confer their properties upon it, and this tendency will increase with increasing percentages of iron. Thus, dross from the galvanizing pot is very different from spelter in its physical properties. It is hard, brittle, has a high melting point, etc.

Lead and Zinc.—The investigations of Spring and Romanoff[1] indicate that at a temperature of about 950° C., lead and zinc would be perfectly miscible in the liquid state. At temperatures



FIG. 9. ×89.

below this, they separate more or less completely into two layers; the amount of zinc in the lower layer, or of lead in the upper layer, being dependent on the temperature. The diagram of thermal equilibrium for the system lead-zinc has been determined by Heycock & Neville,[2] supplemented by the work of Arnemann[3] and is given in Fig. 10. When High Grade spelter—containing say 0.04 per cent lead—cools, zinc, free from lead, first freezes out, and this continues until the concentration of lead in the part remaining liquid reaches 0.5 per cent. This

[1] W. Spring & L. Romanoff, *Zeitschrift für anorganische Chemie*, Vol. 13, p. 29 (1896).
[2] C. T. Heycock & F. Neville, *Journal*, Chemical Society, Vol. 71, p. 394 (1897).
[3] P. T. Arnemann, *Metallurgie*, Vol. 7, p. 204 (1910).

is the limit of solubility of lead and zinc at 418° C., so that any further separation of zinc would cause the limit to be exceeded, and the melt would theoretically separate into two layers as the zinc continued to freeze. As a matter of fact, however, this action does not take place, it being impossible to refine lead-bearing spelter by liquation methods below an extreme lower limit of about 1.0 per cent. The reasons for this are many. In the case of a High Grade spelter, more than 90.0 per cent of the mass is solid when the lead concentration of the liquid portion has reached 0.5 per cent; the lead is released in minute globules; and when we add to this the tendency of all

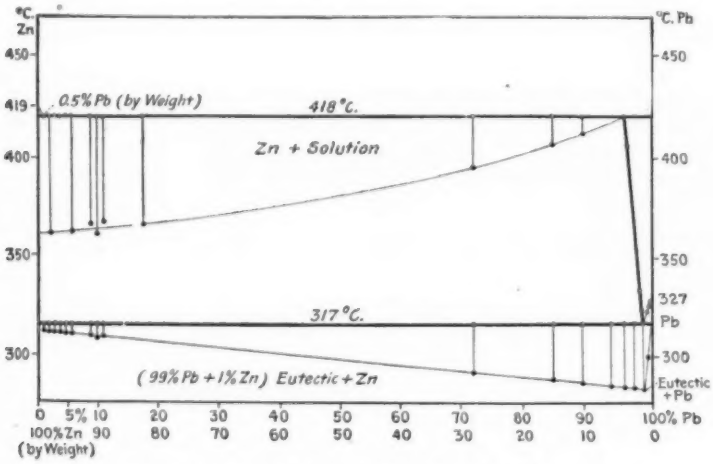


FIG. 10.—Lead-Zinc Diagram, Two Solutions (Arnemann).

liquids to retain fine particles of insoluble matter in suspension it can be readily seen that for purely physical reasons, the lead will remain distributed throughout the spelter.

In the case of Prime Western metal (containing say 1.5 per cent lead) the tendency to separate into two layers would begin at about 425° C. The tendency towards segregation of the lead thus produced is overcome by freezing which soon sets in, causing a more or less regular distribution of the impurity. The lead of course freezes last, together with 1.2 per cent zinc (the eutectic) at a temperature of 317° C. (Arnemann).

Under the microscope the lead appears as small black dots

or globules, while occasionally in high-lead spelters it may be seen as a black network between the grains. Fig 11 is a photograph of a Prime Western spelter containing about 1.5 per cent lead. The lead appears as scattered black dots. Occasionally lead may segregate to the bottom of a slab of high-lead spelter. Fig. 12 is an example of this. The lead globules are very large, and in addition each is surrounded by a ring of small iron-zinc alloy crystals.

The presence of lead in spelter is said to soften it and make it easier to work. The increased malleability observed at about 100° C. in spelter has been attributed by some investigators to the presence of lead.[1]

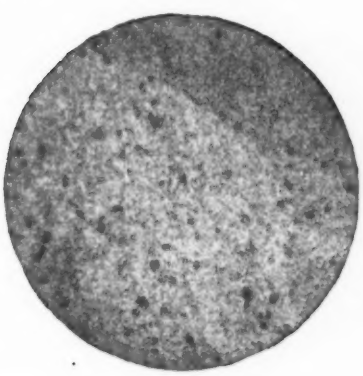


FIG. 11. ×221.

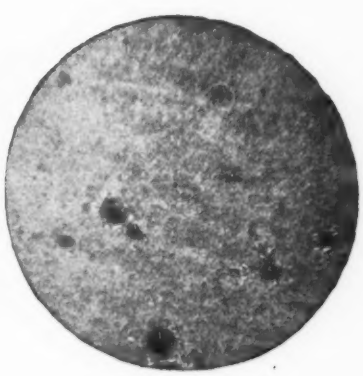


FIG. 12. ×90.

Cadmium and Zinc.—The thermal diagram of the zinc-cadmium system has been determined by several investigators, and the system is given as a simple euctectiferous one (Fig. 13). The addition of small amounts of zinc to cadmium or of cadmium to zinc lowers the freezing point. The eutectic consists of 82.5 per cent of cadmium and 17.5 per cent of zinc, according to Hindricks.[2] Its freezing point is a matter of dispute. Heycock and Neville[3] give 264° C.; Hindricks, 270° C.; while Arnemann[4] found 259°.5 C. to be the freezing temperature. The

[1] C. Benedicks, *Metallurgie*, Vol. 7, p. 531 (1910).
[2] G. Hendricks, *Zeitschrift für anorganische Chemie*, Vol. 55, p. 415 (1907).
[3] C. T. Heycock & F. Neville, *Journal*, Chemical Society, Vol. 71 (1897).
[4] P. T. Arnemann, *Metallurgie*, Vol. 7, p. 204 (1910).

latter explains these disagreements as due to impurities in the cadmium used.

In the case of an alloy containing zinc and cadmium alone, we should therefore expect to obtain (for amounts of cadmium below 82.5 per cent) crystals of zinc separating out first, surrounded by the zinc-cadmium eutectic. Fig. 14 shows this condition for an alloy containing approximately 10 per cent of cadmium, and this structure continues up to a lower limit of about 1 per cent of cadmium. At this point there is a sudden change in structure, as may be seen by reference to Fig. 15,

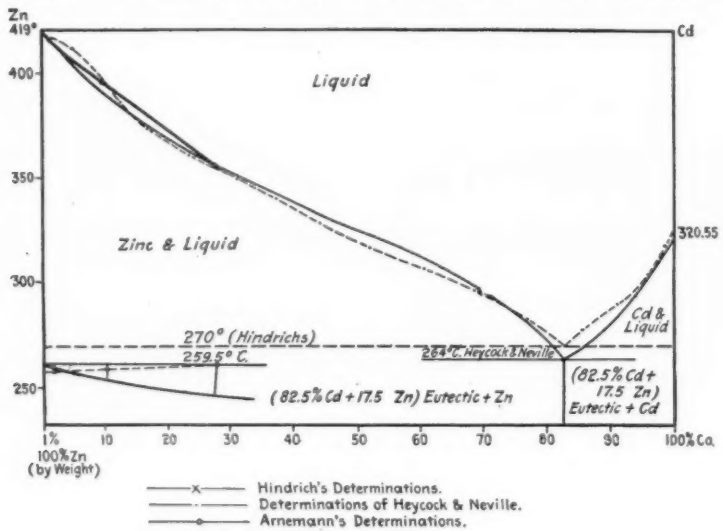


FIG. 13.—Cadmium-Zinc Diagram (Arnemann).

representing an alloy containing about 1 per cent of cadmium. This mottled appearance is characterestic of solid solutions which have been quickly cooled. According to Hindricks, no solid solutions are formed in the zinc-cadmium system, but our observations accord with Arnemann's statement that solid solutions of cadmium in zinc are probably formed up to a limit of about 1 per cent of the former metal.

The presence of cadmium in spelter in amounts between 0.1 and 1 per cent may easily be determined on a polished specimen without recourse to the microscope. Such specimens have

a strong tendency to stain brown when etched with dilute nitric acid in alcohol, and in addition, the non-homogeneous solid solutions produce an acicular appearance on the surface of an etched specimen which is highly characteristic.

Solid solutions are generally as strong as pure metals, if not stronger. Therefore the presence of cadmium in the amounts generally found in spelters should not weaken the metal.

Commercial Zinc or Spelter.—Spelter usually contains the three impurities we have just considered, namely, iron, lead, and cadmium; the quality of the spelter being determined by

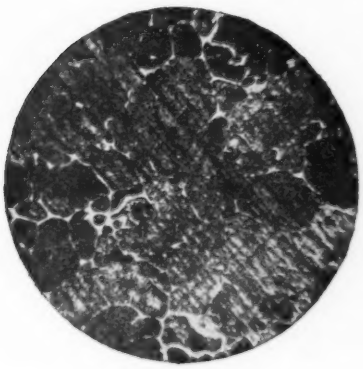


FIG. 14. ×64.

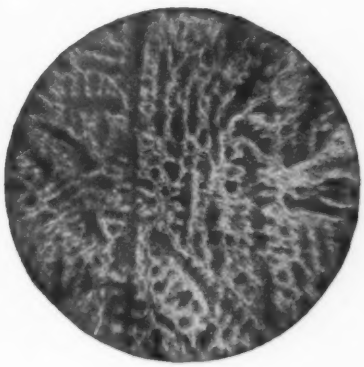


FIG. 15. ×14.

the amounts of the impurities present. In addition to the common impurities named, spelter may contain small amounts of other metallic impurities including arsenic, antimony, tin, copper, and bismuth. These latter, with the exception of arsenic, are much more uncommon, however.

Examined under the microscope, High Grade spelter presents a fairly homogeneous appearance. The lead present is very sparingly distributed as very fine globules, and occasionally a small crystal of iron-zinc alloy is to be seen. Fig. 1 shows the coarse, and Fig. 2 the fine crystallization of this metal.

The lead in Prime Western spelter generally occurs in globules which are much more numerous than in the case of High Grade, Intermediate, or Brass Special metal. The amount

of iron alloy crystals present will of course depend on the varying iron content of the spelter. The presence or absence of the solid solutions of cadmium will depend on the cadmium content of the spelter. Fig. 11 shows the lead globules well. Fig. 16, a spelter somewhat high in iron and cadmium, shows the characteristic mottled appearance due to solid solutions of the latter metal, also numerous small white iron-zinc alloy crystals.

TEST SPECIMENS.

Zinc, as is well known, acts as a ductile material in compression, but as a brittle material in tension. It was therefore

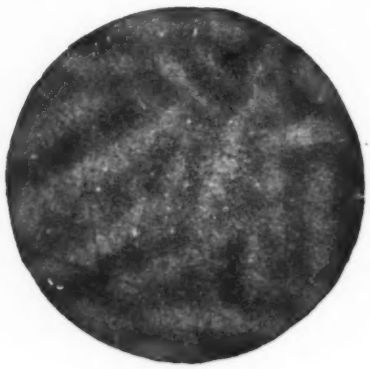


FIG. 16. ×42.

thought desirable to make both tension and compression tests on the metal, and transverse tests were also added.

All test specimens were prepared as follows:

The slabs of the metal to be tested were broken in smali pieces. Two bars were cast at a time, the material being melted up in a Dixon plumbago crucible holding about 15 lb. of spelter. The melting was accomplished in a small coke furnace, and during the melting the crucible was kept covered to avoid contamination from the coke. After the metal was well melted, but not so hot as to be in danger of burning, it was removed from the furnace, and the temperature allowed to fall to 480° C., the temperature being observed by means of a platinum - platinum-iridium thermo couple. The metal was

then poured into the molds, allowed to solidify, and the resulting test bar removed by lifting out. Before pouring the test bars the metal was skimmed with a wooden skimmer, and thoroughly stirred with a silica rod, to avoid danger of segregation of impurities.

The molds were made in halves, and of cast iron. They were $5\frac{1}{4}$ in. square by 19 in. deep. At the center a hole, $1\frac{1}{4}$ in. in diam. and $17\frac{1}{2}$ in. deep was drilled for the test bars. The molds were always cold when the metal was poured in them and the bar solidified in a few seconds. The molds did vary slightly in temperature, but if more than slightly warm to the hand they were cooled before using. It was found that it was not necessary to separate the mold in order to remove the test bar the slight contraction taking place permitting the bar to be withdrawn by lifting out of the top of the mold.

In this way eight bars were cast for each kind of spelter to be tested, two being cast from each melt. The test bars as cast were $17\frac{1}{2}$ in. long and approximately $1\frac{1}{4}$ in. in diameter. The surface was not perfectly smooth, due to the chilling of part of the metal on pouring, but was nearly so. The bars were almost free from blow holes; occasionally a small one was run across in the turning.

Of the eight bars cast, two were set aside as reserve samples. Four others were taken and the upper $2\frac{1}{2}$ in. containing the pipe was cut off with a hack-saw. The remainder of the bar was used for the transverse tests, while the upper portion was sent to the laboratory for analysis. The analyses were conducted on turnings made from the cut-off ends of these four bars

From the remaining two bars the tension and compression test specimens were machined, two tension and two compression specimens from each bar. In machining, the upper $2\frac{1}{2}$ in. of the bars containing the pipe was avoided. The tension specimens were turned like the American Society for Testing Materials standard tension test specimens for cast iron, the compression specimens were plain cylinders 1 in. in diameter and 2.6 in. long.

In addition to High Grade, Intermediate, Brass Special, and Prime Western spelters, test bars were also cast from Galvanizing Pot dross for the sake of comparison. On account of

the higher melting point of dross it was necessary to cast these bars at 700° C. During the melting considerable zinc was lost by oxidation; so, in the case of the dross bars, the material from each melt was analyzed separately.

METHODS OF TESTING.

The results of the anaylses of the turnings from the tops of the test bars are given in Table I. All the material was fairly

TABLE I.—ANALYSES.

Grade of Spelter.	Sample.	Made from	Analysis, per cent.			
			Zinc.	Lead.	Iron.	Cadmium.
High Grade	First	Silicate	99.95[a]	0.041	0.014	None
High Grade	Second	Silicate	99.94[a]	0.040	0.016	None
Intermediate	First	Silicate	99.79[a]	0.194	0.016	None
Intermediate	Second	Silicate	99.79[a]	0.190	0.017	None
Brass Specinl	First	Silicate	99.51[a]	0.474	0.013	None
Brass Special	Second	Silicate	99.48[a]	0.484	0.031	None
Prime Western No. 1	First	Colorado Blende	98.48[a]	1.19	0.032	0.250
Prime Western No. 1	Second	Colorado Blende	98.41[a]	1.42	0.087	0.079
Prime Western No. 2	First	Wisconsin Blende	99.04[a]	0.68	0.010	0.274
Prime Western No. 2	Second	Wisconsin Blende.	98.79[a]	1.15	0.011	0.046
Dross No. 1			94.7	1.74	3.62	0.012
Dross No. 2			94.2	2.06	3.75	0.041
Dross No. 3			94.3	2.70	3.05	0.088
Dross No. 4			94.5	1.89	3.63	0.031

[a] Analyses are by difference.

representative of the average run of that grade of spelter, the only exception being the Prime Western No. 1, second sample, which is somewhat high in iron.

All the tests were carried out in the testing laboratory of the Department of Civil Engineering, Columbia University, New York, the testing being done by Mr. Harold Perrine in the presence of one of us. The methods of testing are briefly described below.

Tension Tests.—These tests were carried out with the

Riehlé 100,000-lb. machine. The maximum (breaking) load only was observed, the elongation being practically nil. The speed of testing was about 0.1 in. per minute.

Transverse Tests.—For these, the Olsen 50,000-lb. machine was used, the supports being 12 in. apart and the load applied at the center. The load was applied continuously, the amount of deformation being read at the moment of the appearance of the first crack at the bottom of the test specimen (observed by a mirror). Deformations were read by means of a deflectometer graduated to 0.001 in., but read to 0.01 in. only. The speed of testing was somewhat high—about 0.55 in. per minute.

Compression Tests.—In order to avoid irregularities due to variations in the speed of testing, the following method of making these tests was used. The Olsen 400,000-lb. machine, which could be run at a very slow rate of speed, was used for the tests. A load of 100 lb. was applied to the specimen and the deflectometer adjusted to zero. The machine was then started, and the load applied at a constant rate of speed of 0.0319 in. per minute. Deformations were read to 0.001 in. by means of a deflectometer for each increment of load (500 or 1000 lb.), the reading being taken just as the beam of the machine lifted. The strains were noted without interrupting the movement of the head of the machine until a compression of 20 per cent was attained; the amount of load corresponding to this figure being noted on the beam arm of the machine. By this method errors due to variations in speed were entirely eliminated.

RESULTS OF TESTS.

Tension Tests.—Table II shows the results of these tests. It will be noted that the tensile strength as figured from the maximum load varies very widely even in the case of individual specimens of one grade of metal. Thus, in the case of Prime Western No. 1, first sample, we have for a minimum of tensile strength, 4198 lb. per sq. in., while the maximum figure for the same grade of metal was 10,444 lb. per sq. in.—a variation of nearly 150 per cent. In most cases these variations could be explained by differences in the size of the crystals in the test specimen. As has already been stated, the molds varied but

TABLE II.—RESULTS OF TENSION TESTS.

All specimens turned like A. S. T. M. Standard for Cast-Iron Specimens. Riehlé 100,000-lb. machine used; Speed of testing, 0.1 in. per minute.

Grade of Spelter.	Sample.	Diameter, in.	Area, sq. in.	Maximum Load, lb.	Ultimate Strength, lb. per sq. in.	Remarks.
High Grade.....	First....	0.800	0.5027	2 060	4 098	
" "	"	0.800	0.5027	2 660	5 292	
" "	"	0.800	0.5027	4 140	8 236	Finely crystalline.
" "	"	0.800	0.5027	3 730	7 420	Crystals somewhat fine.
High Grade.....	Second ..	0.800	0.5027	2 070	4 118	
" "	" ..	0.800	0.5027	2 500	4 973	
" "	" ..	0.799	0.5014	2 060	4 109	
" "	" ..	0.800	0.5027	2 070	4 118	
Intermediate.....	First....	0.800	0.5027	2 740	5 451	
"	"	0.800	0.5027	1 880	3 740	
"	"	0.800	0.5027	1 880	3 740	
"	"	0.800	0.5027	2 330	4 436	
Intermediate.....	Second..	0.800	0.5027	3 060	6 088	
"	" ..	0.800	0.5027	2 610	5 192	
"	" ..	0.799	0.5014	2 250	4 487	
"	" ..	0.800	0.5027	2 320	4 615	
Brass Special.....	First....	0.800	0.5027	5 320	10 584	Fine crystals.
" "	"	0.800	0.5027	5 090	10 125	" "
" "	"	0.799	0.5014	6 930	13 821	Very fine crystals.
" "	"	0.800	0.5027	6 730	13 388	" " "
Brass Special.....	Second..	0.800	0.5027	2 060	4 098	
" "	" ..	0.800	0.5027	1 790	3 561	Crystals somewhat coarse.
" "	" ..	0.800	0.5027	2 690	5 351	
" "	" ..	0.800	0.5027	2 170	4 317	
Prime Western No. 1.	First....	0.800	0.5027	4 690	9 330	Fine crystals.
" " No. 1.	"	0.800	0.5027	2 110	4 198	
" " No. 1.	"	0.800	0.5027	5 250	10 444	Fine crystals.
" " No. 1.	"	0.799	0.5014	3 450	6 881	
Prime Western No. 1.	Second..	0.800	0.5027	1 500	2 984	Coarse crystals.
" " No. 1.	" ..	0.799	0.5014	1 750	3 490	
" " No. 1.	" ..	0.800	0.5027	1 990	3 959	
" " No. 1.	" ..	0.800	0.5027	2 200	4 377	
Prime Western No. 2.	First....	0.799	0.5014	6 790	13 543	Very fine crystals.
" " No. 2.	"	0 800	0.5027	5 910	11 757	Fine crystals.
" " No. 2.	"	0.800	0.5027	3 580	7 122	Crystals somewhat coarse.
" " No. 2.	"	0.800	0.5027	5 410	10 762	Fine crystals.
Prime Western No. 2.	Second..	0.800	0.5027	1 830	3 640	Coarse crystals.
" " No. 2.	" ..	0.800	0.5027	2 680	5 331	
" " No. 2.	" ..	0.800	0.5027	2 420	4 814	
" " No. 2.	" ..	0.800	0.5027	2 470	4 914	
Dross No. 2.....	.....	0.800	0.5027	4 090	8 136	
" No. 2.....	.....	0.800	0.5027	3 180	6 326	
" No. 4.....	.....	0.800	0.5027	3 800	7 559	Numerous blow holes.

slightly in temperature, and the results of the tests would therefore seem to show quite clearly that, in order to secure reliable results of tension tests with a highly crystalline and brittle metal like zinc, it is absolutely essential that all melts should be cast at exactly the same temperature; and furthermore, that the molds should always be at exactly the same temperature. Without these precautions slight variations in the crystal size will take place, causing comparatively large variations in the tensile



FIG. 17.—Tension Pieces.

strength of the metal. Fig. 17 is a photograph of two of the test specimens of the same grade of spelter and sample (Prime Western No. 2, first sample). The test specimens on the left (finely crystalline) gave a tensile strength of 13,543 lb. per sq. in.; while that on the right, which is somewhat more coarsely crystalline than the average run of test specimens gave a tensile strength of only 7122 lb. per sq. in.

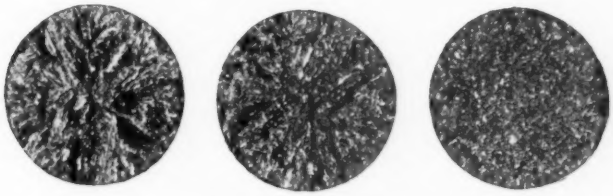


FIG. 18.—Test Bars.

By referring to Table V (Plate XIX) under the section headed "Tension," the averages for these tests can be seen. As long as the spelter is fairly pure, the tensile strength seems to be almost entirely a function of the size and mode of growth of the crystals.

Transverse Tests.—The results of the transverse tests are given in Table III. In the last column, the moduli of rupture in pounds per square inch are given for the various specimens tested.

TABLE III.—RESULTS OF TRANSVERSE TESTS.

All specimens Circular Rods, cast upright in cold iron molds.
Olsen 50,000-lb. machine used.
Distance between supports, 12 in. in all cases.
Load applied at center—Speed of testing about 0.55 in. per minute.

Modulus of Rupture $= R = \frac{Wl}{\pi r^3}$, where W = load in lbs.,

l = distance between supports, in., and r = radius of test specimens, in.

Grade of Spelter.	Sample.	Diameter, in.	Total Deflection, in.	Maximum Load, lb.	Modulus of Rupture, lb. per sq. in.
High Grade	First	1.237	....	710	11 450
" "	"	1.250	0.28	710	11 100
" "	"	1.247	0.22	750	11 810
" "	"	1.241	0.26	760	12 150
High Grade	Second	1.243	0.25	660	10 500
" "	"	1.242	0.30	670	10 680
" "	"	1.242	0.20	630	10 040
" "	"	1.240	0.24	690	11 060
Intermediate	First	1.243	0.26	670	10 660
"	"	1.246	0.33	650	10 270
"	"	1.239	0.26	600	9 640
"	"	1.234	0.36	620	10 080
Intermediate	Second	1 234	0.33	850	13 820
"	"	1.242	0.33	820	13 060
"	"	1.240	0.44	790	12 660
"	"	1.234	0.15	610	9 930[a]
Brass Special	First	1.232	0.25	990	16 200[b]
" "	"	1.241	0.32	1 010	16 140[b]
" "	"	1.237	0.16	720	11 620
" "	"	1.235	0.43	1 370	22 220[d]
Brass Special	Second	1.234	0.28	1 000	16 260[b]
" "	"	1.236	0.17	530	8 580[c]
" "	"	1.239	0.24	1 010	16 230[b]
" "	"	1.241	0.16	710	11 350
Prime Western No. 1	First	1.240	0.12	800	12 830
" " No. 1	"	1.242	0.16	530	8 440[c]
" " No. 1	"	1.235	0.09	760	12 320
" " No. 1	"	1.237	0.13	650	10 490
Prime Western No. 1	Second	1.246	0.20[e]	600	9 480[e]
" " No. 1	"	1.235	0.11	580	9 400[e]
" " No. 1	"	1.227	0.11	650	10 750
" " No. 1	"	1.240	0.10	660	10 580
Prime Western No. 2	First	1.241	0.19	1 150	18 390[b]
" " No. 2	"	1.239	0.16	930	14 940
" " No. 2	"	1.240	0.17	830	13 300
" " No. 2	"	1.231	0.18	1 120	18 350[b]
Prime Western No. 2	Second	1.227	0.22	640	10 590
" " No. 2	"	1.247	0.19	720	11 350
" " No. 2	"	1.238	0.18	630	10 130
" " No. 2	"	1.243	0.17	590	9 390[c]
Dross No. 1	.....	1.244	0.07	1 000	15 880
" No. 2	.....	1.234	0.04	950	15 450
" No. 3	.....	1.236	0.04	850	13 750
" No. 4	.....	1.234	0.04	990	16 100[a]

[a] Numerous blow holes.
[b] Finely crystalline.
[c] Coarse crystals.
[d] Very finely crystalline.
[e] Reading of deflectometer probably high due to crack not appearing in center of specimen.

As in the case of the tension tests it will be seen that tne moduli, even as determined for the same grade of spelter and the same sample, vary quite widely, although the percentage variations are not as great as in the case of the tension tests. Again, the explanation of these variations is to be found in the size of the crystals making up the test specimens. Fig. 18 is a photograph showing the broken ends of three of the specimens. The one on the left is coarsely crystalline; that in the center shows the usual crystallization of the bars (as also that of the tension test specimens); while the specimen on the right is finely crystalline. The average moduli are given under the section headed "Flexure," Table V. Eliminating averages which are too high or too low to be comparable (due to very fine or very coarse crystallization), the average values agree fairly closely and average about 11,320 lb. per sq. in. The dross specimens give a somewhat higher average—15,300 lb. per sq. in. As with the tension tests, it is evident here also that moduli of rupture determined by transverse test will not be very useful for application to this highly crystalline material.

Turning to the fourth column of Table III, showing the total deflection of the various grades of spelter, we begin to get much closer correspondence in the figures. The averages are given in Table V. and from them we see that:

1. Very impure zinc (dross) gives very small deflections when tested transversely, averaging 0.05 in.;

2. Ordinary (Western) spelters give deflections averaging 0.13 to 0.19 in.;

3. Purer (High Grade, Intermediate, and Brass Special) spelters give the highest deflections of all, averaging from 0.21 to 0.31 in.; and running as high as 0.44 in.

Compression Tests.—These tests were run as already described, and gave by far the most satisfactory results of any of the three methods of testing. The compressive strengths of the various test specimens at 10 and 20-per-cent compression are given in Table IV, the deflectometer readings for these tests are plotted in detail and given in Figs. 19 to 25, inclusive. The loads at 10-per-cent compression, not being read directly, were determined by interpolation. At 10-per-cent compression, the specimens still held their shape fairly well;

TABLE IV.—RESULTS OF COMPRESSION TESTS.

All specimens Plain Cylinders, tested on end—2.6 in. long.
Olsen 400,000-lb. machine used. Speed of testing, 0.0319 in. per minute.

No.	Grade of Spelter.	Sample.	Diameter, in.	Area, sq. in.	Load at 10 per cent. comp., lb.	Load at 20 per cent. comp., lb.	Strength at 10 per cent. comp., lb. per sq. in.	Strength at 20 per cent comp., lb. per sq. in.	Remarks.
1	High Grade	First	1.000	0.7854	13 400	19 200	17 060	24 450	
2	" "	"	1.000	0.7854	13 910	19 700	17 710	25 080	
3	" "	"	0.999	0.7838	11 890	18 710	15 170	23 870	
4	" "	"	0.999	0.7838	12 890	18 420	16 440	23 500	
1	High Grade	Second	1.000	0.7854	12 670	18 400	16 130	23 430	
2	" "	"	1.000	0.7854	12 850	18 460	16 360	23 500	
3	" "	"	1.000	0.7854	.....[1]	18 850	16 700	24 000	10 per cent strength approximate.
1	Intermediate	First	1.000	0.7854	13 650	19 050	17 380	24 260	
2	"	"	1.000	0.7854	12 070	17 590	15 370	22 400	
3	"	"	1.000	0.7854	11 900	17 360	15 150	22 100	
4	"	"	1.000	0.7854	12 630	18 350	16 080	23 360	
1	Intermediate	Second	1.000	0.7854	13 490	18 810	17 180	23 950	
2	"	"	1.000	0.7854	11 920	17 400	15 180	22 150	
3	"	"	0.999	0.7838	12 130	17 770	15 480	22 670	
4	"	"	0.999	0.7838	13 070	18 670	16 680	23 820	
1	Brass Special	First	1.000	0.7854	14 920	21 430	19 000	27 290	
3	" "	"	0.999	0.7838	15 450	21 860	19 710	27 890	
2	" "	"	1.000	0.7854	16 340	22 390	20 800	28 510	
4	" "	"	0.999	0.7838	16 390	22 400	20 910	28 580	
1	Brass Special	Second	0.999	0.7838	14 130	20 120	18 030	25 670	
2	" "	"	1.000	0.7854	12 720	18 600	16 190	23 680	
3	" "	"	1.000	0.7854	13 960	19 750	17 770	25 140	
4	" "	"	1.000	0.7854	13 190	19 500	16 790	24 830	
1	Prime Western No. 1	First	1.000	0.7854	21 370	30 480	27 210	38 810	
2	" " No. 1	"	1.000	0.7854	23 130	30 530	29 450	38 870	
3	" " No. 1	"	1.000	0.7854	22 860	30 350	29 110	38 640	
4	" " No. 1	"	1.000	0.7854	21 450	30 440	27 310	38 760	
1	Prime Western No. 1	Second	1.000	0.7854	17 890	24 650	22 780	31 390	
4	" " No. 1	"	0.999	0.7838	15 690	22 950	20 020	29 280	
2	" " No. 1	"	1.000	0.7854	15 950	23 000	20 310	29 280	
3	" " No. 1	"	1.000	0.7854	16 250	23 500	20 690	29 920	
1	Prime Western No. 2	First	1.000	0.7854	21 240	30 440	27 040	38 760	
4	" " No. 2	"	1.000	0.7854	22 010	30 910	28 020	39 360	
2	" " No. 2	"	0.999	0.7838	23 450	31 250	29 920	39 870	
3	" " No. 2	"	1.000	0.7854	23 430	31 400	29 830	39 980	
1	Prime Western No. 2	Second	0.999	0.7838	13 880	20 950	17 710	26 730	
2	" " No. 2	"	1.000	0.7854	16 850	22 960	21 450	29 230	
3	" " No. 2	"	1.000	0.7854	14 970	21 860	19 060	27 830	
4	" " No. 2	"	0.998	0.7823	17 270	23 460	22 080	29 990	

						Max. Load, lb.		Max. Str., lb. per sq. in.	
1	Dross No. 2	.....	1.000	0.7854	.....	25 100	.....	31 960	Failed by swelling and cracking.
2	" No. 2	.....	0.999	0.7838	28 020	28 740	35 750	36 670	
1	Dross No. 4	.....	0.999	0.7838	28 120	30 200	35 880	38 530	Failed by swelling and cracking.
2	" No. 4	.....	0.999	0.7838	.....	23 800	.....	30 360	

[1] Screw of deflectometer hit block, causing incorrect reading. For results of these tests in detail see Figs. 19–25, inclusive.

at 20-per-cent compression, the circular sections of the specimens had become more or less irregular in shape; the cross-sectional area had appreciably increased; and in addition several of the specimens were slightly bent, or were even in double flexure. For this reason, although the ninth column of Table IV gives the 20-per-cent compressive strength, per square inch of *original cross-section*, the results in the eighth column giving the strength at 10-per-cent compression are more

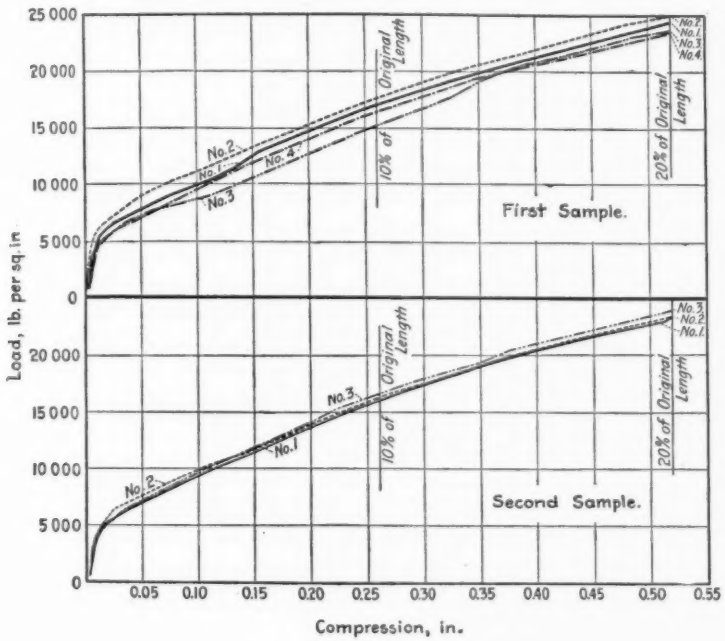


FIG. 19.—High Grade No. 1.

reliable. It will be noted that the results for each of the various grades and samples check remarkably well, and furthermore that considerable differences in the spelters are shown. In the case of the dross, complete failure took place in all cases before a 20-per-cent compression had been reached; in two cases, failure took place before the specimens had been compressed 10 per cent. This failure consisted in a swelling of part of the specimen accompanied by cracking. For the dross, therefore, the

maximum loads are given. None of the spelter specimens could be said to have failed completely, since increase of load produces an increased area due to deformation, and therefore greater resistance.

It may be interesting to note, in this connection, that before starting these tests, two cylinders of High Grade spelter, of the same dimensions as the test specimens used in these tests, were loaded up to 60,000 lb. Under these conditions, the

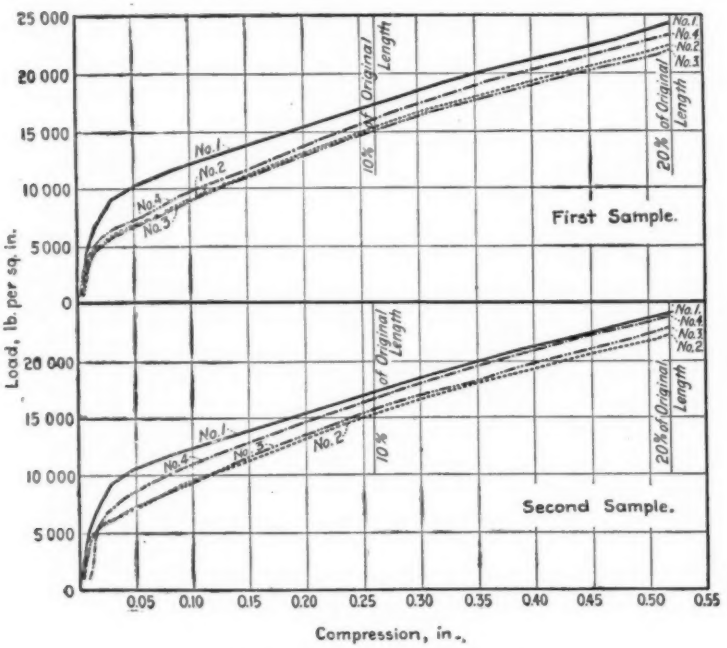


FIG. 20.—Intermediate No. 1.

cylinders were compressed to a height of 0.8 in. At a load of about 50,000 lb., the specimens developed cracks, but upon investigation these cracks seemed to be due more to the friction of the plates on the head of the machine (preventing free lateral movement of the particles) than to true shearing. Now for an original cross-sectional area of 0.7854 sq. in., a load of 60,000 lb. corresponds to a pressure of about 76,400 lb. per sq. in. It is very evident, however, that on account of the increased cross-sectional

Material.					Tension.			
Grade.	Sample.	Analyses, per cent.			Ultimate Strength, lb. per sq. in.			Remarks.
		Pb	Fe	Cd	Maximum.	Minimum.	Average.	
High Grade.....	First....	0.041	0.014	None	8 236	4 098	6 262	Specimen giving maximum value finely crystalline. Average somewhat high.
High Grade.....	Second..	0.040	0.016	None	4 973	4 109	4 330	.....
Intermediate.....	First....	0.194	0.016	None	5 451	3 740	4 340	.....
Intermediate.....	Second..	0.190	0.017	None	6 088	4 487	5 095	.....
Brass Special.....	First....	0.474	0.013	None	13 821	10 125	11 980	All finely crystalline giving high average.
Brass Special.....	Second..	0.484	0.031	None	5 351	4 098	4 330	Crystals somewhat coarse. Average, therefore, low.
Prime Western No. 1..	First....	1.19	0.032	0.250	10 444	4 198	7 710	Specimen giving maximum value finely crystalline.
Prime Western No. 1..	Second..	1.42	0.087	0.079	4 377	2 984	3 700	Minimum—coarsely crystalline...
Prime Western No. 2..	First....	0.68	0.010	0.274	13 543	7 122	10 800	Three Specimens finely crystalline, giving high average.
Prime Western No. 2..	Second..	1.15	0.011	0.046	5 331	3 640	4 670	Minimum—coarsely crystalline...
Dross.....	.....	2.09	3.51	0.043	8 136	6 326	7 340	Mean of three.....

TABLE V.—SUMMARY OF RESULTS.

ENSION.	FLEXURE.							
Remarks.	Modulus of Rupture, lb. per sq. in.			Remarks.	Total Deflection on 12-in. Span, in.			I
	Maximum.	Minimum.	Average.		Maximum.	Minimum.	Average.	
Specimen giving maximum value finely crystalline. Average somewhat high.	12 150	11 100	11 630	.....	0.28	0.22	0.25	Mean c
.....	11 060	10 040	10 570	.....	0.30	0.20	0.25	.....
.....	10 660	9 640	10 160	.....	0.36	0.26	0.30	.....
.....	13 820	9 930	12 360	.....	0.44	0.15	0.31	.....
All finely crystalline giving high average.	22 220	11 620	16 550	Specimen giving maximum very finely crystalline. Mean high due to fine crystals.	0.43	0.16	0.29	.....
Crystals somewhat coarse. Average, therefore, low.	16 260	8 580	13 110	Maximum—finely crystalline. Minimum—coarse crystals.	0.28	0.16	0.21	.....
Specimen giving maximum value finely crystalline.	12 830	8 440	11 020	Minimum—coarsely crystalline.	0.16	0.09	0.13	.....
Minimum—coarsely crystalline...	10 750	9 400	10 050	Minimum—coarsely crystalline. Mean probably somewhat too low.	0.20	0.10	0.13	Maxim
Three Specimens finely crystalline, giving high average.	18 390	13 300	16 250	Maximum—finely crystalline. Mean probably somewhat too high.	0.19	0.16	0.18	.....
Minimum—coarsely crystalline...	11 350	9 390	10 370	Minimum—coarsely crystalline.	0.22	0.17	0.19	.....
Mean of three.....	16 100	13 750	15 300	.....	0.07	0.04	0.05	.....

		COMPRESSION.							
		Strength at 10-per-cent Compression, lb. per sq. in.				Strength at 20-per-cent Compression, lb. per sq. in.			
on ver-ge.	Remarks.	Maximum.	Minimum.	Average.	Remarks.	Maximum.	Minimum.	Average.	Remarks.
.25	Mean of three.....	17 710	15 170	16 600	.....	25 080	23 500	24 230	
.25	.....	16 700	16 130	16 400	Three specimens tested....	24 000	23 430	23 640	Three tested.
.30	.....	17 380	15 150	16 000	.....	24 260	22 100	23 030	
.31	.....	17 180	15 180	16 130	.....	23 950	22 150	23 150	
.29	.....	20 910	19 000	20 110	.....	28 580	27 290	28 070	
.21	.....	18 030	16 190	17 190	.....	25 670	23 680	24 830	
.13	.....	29 450	27 210	28 270	.....	38 870	38 640	38 770	
.13	Maximum doubtful...	22 780	20 020	20 950	.....	31 390	29 280	29 970	
.18	.....	29 920	27 040	28 700	.....	39 980	38 760	39 490	
.19	.....	22 080	17 710	20 080	.....	29 990	26 730	28 450	
						Max. Load, lb. per sq. in.			
.05	.....	35 880	35 750	35 820	Two failed before reaching 10 per cent.	38 530	30 360	34 380	Failed completely.

area of the specimens, they were not carrying anything approximating this load. Assuming that the volume of the spelter has not been materially changed by the compression, a height of 0.8 in. will mean an average cross-section of 2.5526 sq. in. for a specimen originally 2.6 in. long and 1 in. in diameter. Dividing this figure into the load we obtain about 23,500 lb. per sq. in. as the load. As a matter of fact, the load is probably even less

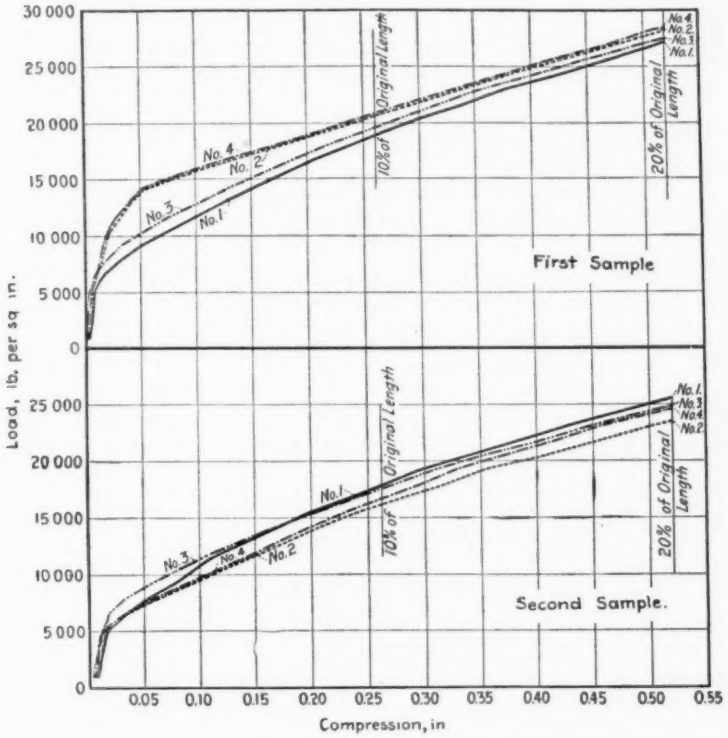


FIG. 21.—Brass Special No. 1.

than this, and represents that pressure at which zinc will continue to flow indefinitely as long as the pressure is applied. By reference to Table IV, it can be seen that this figure has been exceeded in most cases in the case of the High Grade metal. Therefore, tests carried out above a compression of say 20 per cent can throw but little light on the physical properties of the spelter.

By referring now to Table V (Plate XIX) under the section headed "Compression," we have the averages of the results given in Table IV. Taking the strengths at 10-per-cent compression, we have for the High Grade and Intermediate spelters figures vary-

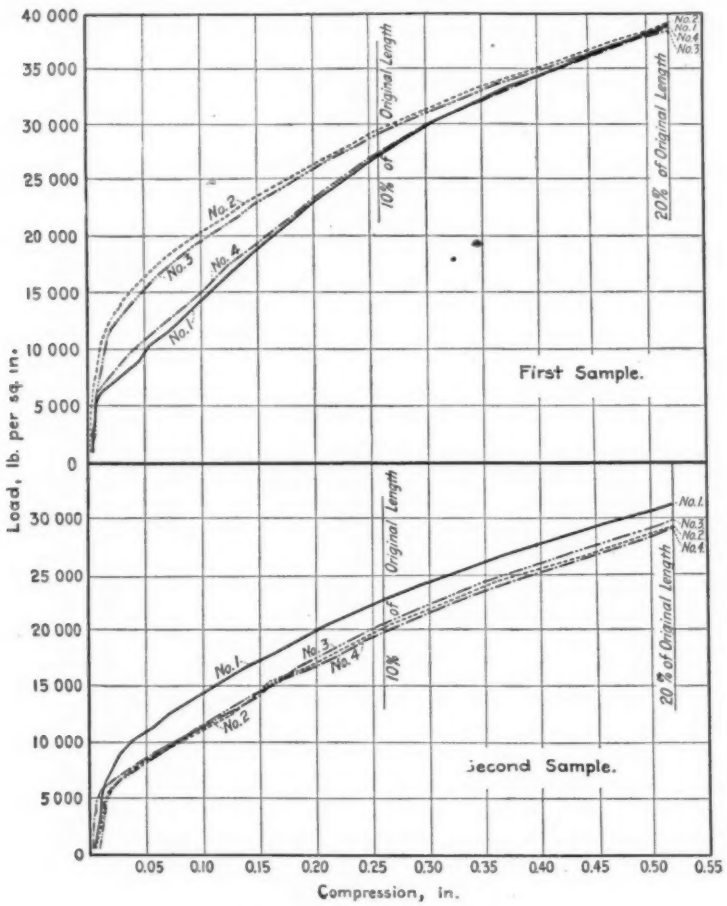


FIG. 22.—Prime Western No. 1.

ing between 16,000 and 16,600 lb. per sq. in. The Brass Special, first sample, gives a somewhat higher figure—20,100 lb. per sq. in.—which drops, in the case of the second sample, to 17,190 lb. per sq. in. This higher value, exhibited by the first sample, might be due to either of two causes: (1) To a somewhat finer

crystal structure of the first, as previously exhibited by the transverse and tension specimens, and (2) to differences in composition between the two. In the latter case, the increased compressive strength of the first sample would probably be due to the presence of a trace of cadmium, not shown in the analysis.

Both the Prime Western metals, first sample, show a relatively high compressive strength at 10-per-cent compression—28,270 lb. per sq. in. for No. 1, and 28,700 lb. per sq. in. for No. 2. The second-sample metals show a drop in compressive strength—20,950 lb. per sq. in. for No. 1, and 20,080 lb. per sq. in. for No. 2.

This second sample metal is higher in lead, lower in cadmium, and higher in iron than the first. Which of these variations has had the greatest effect in reducing the compressive strength, and to the presence of which impurities must we ascribe the greater compressive strength of Western spelters? Dross gives a compressive strength of 35,820 lb. per sq. in. at 10-per-cent compression. We further know that iron hardens spelter. However, the iron content of the second sample, Prime Western No. 1, has materially increased, and yet the compressive strength has dropped materially. The variation in lead content has been relatively small—only 0.2 per cent. The cadmium content, however, has shown a considerable decrease in the case of the second sample metal.

In the case of the Prime Western No. 2, the cadmium variation is also very large; 0.274 per cent for the first sample and 0.046 per cent for the second. We give below the analyses of Brass Special, second sample, and Prime Western No. 2, first sample, and their strengths at 10-per-cent compression:

Grade of Spelter.	Analyses, per cent.			Average Strength at 10-per-cent Compression, lb. per sq. in.
	Fe.	Pb.	Cd.	
Brass Special, second sample	0.031	0.484	None	17 190
Prime Western No. 2, first sample	0.010	0.680	0.274	28 700

Here the only great difference is in the cadmium content; the compressive strengths are, however, quite different and the results are even more striking when the compression curves are compared. (Fig. 21, second sample, and Fig. 23, first sample.) The fact that the presence of a small amount of cadmium will

greatly increase the compressive strength of zinc is in accord with earlier tests that we have made on the metal.[1]

The facts would therefore seem to justify the assumption that the greater part of the increased resistance in compression

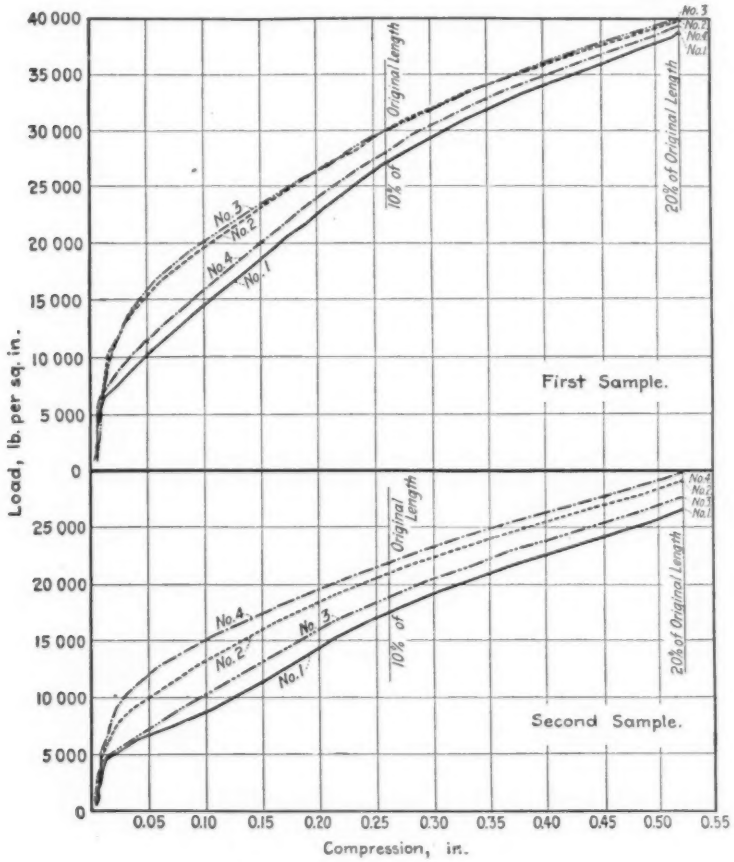


FIG. 23.—Prime Western No. 2.

of Western spelters is due to their cadmium content. At any rate it seems probable that the presence of a small amount of

[1] Made by us on two lots of Brass Special spelter, test specimens cut from slabs. Lot No. 1 contained no cadmium, lot No. 2 contained traces of cadmium. Compressive strengths at 10-per-cent compression:

Lot No. 1—(Avg. of 3)—16,418 lb. per sq. in.

Lot No. 2—(Avg. of 3)—21,903 lb. per sq. in.

cadmium has a greater effect on the physical properties of spelter than has generally been supposed.

The figures for 20-per-cent compression vary in the same manner as those for 10-per-cent compression.

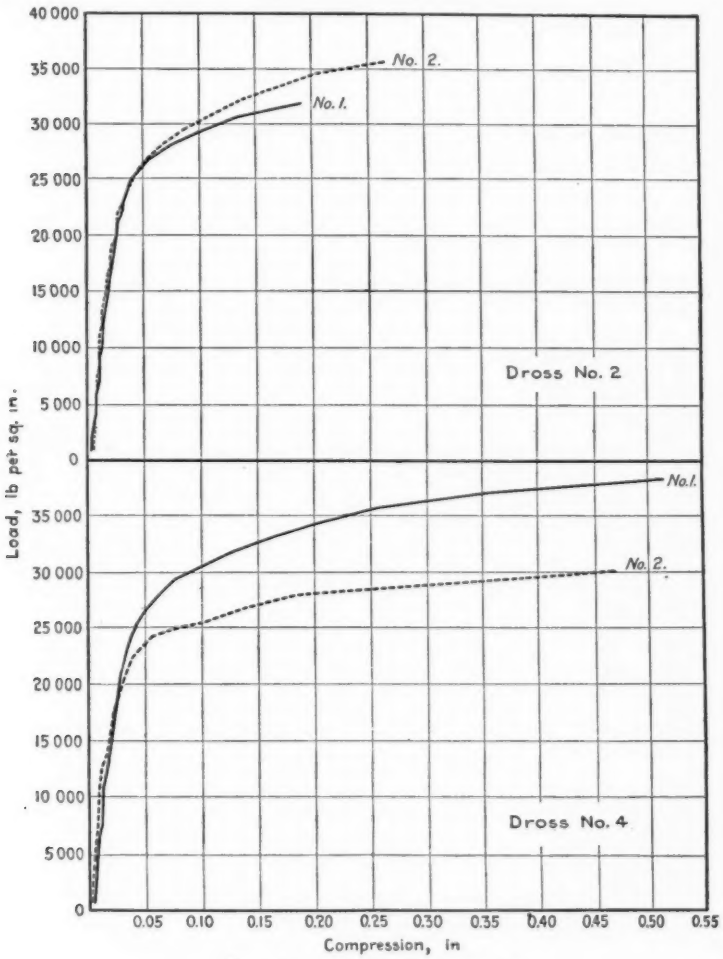


FIG. 24.—Dross Nos. 2 and 4.

Again, by reference to the compression diagrams it will be seen that in some cases, one or two of the test specimens were much more resistant at the beginning of the test. This is especially well marked in Fig. 21, first sample, showing Brass

Special metal. Two of the specimens are highly resistant at the beginning of the compression; the other two show greater deformations. The curves are, however, quite close together at 10 and 20-per-cent compression. This greater resistance at the start might be due to any one of the three following causes: (1) Variations in composition; (2) greater speed of testing; (3) differences in crystal structure.

Variations in composition are not likely to take place in as pure a spelter as Brass Special. The speed of testing was in

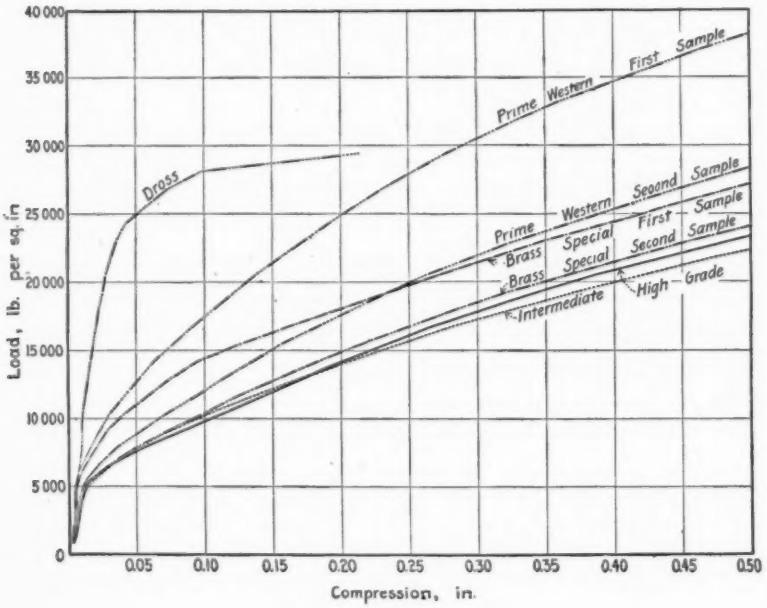


FIG. 25.—Average Compressions.

all cases the same, so this variation in the shape of the curves is more probably due to a difference in crystal structure of the test specimens; the more resistant pieces having the finer crystal structure. This is more than likely, inasmuch as several of the tension and transverse specimens of this particular metal and sample were finely crystalline.

The curves for dross as given in Fig. 24 are entirely different from those for spelter. This material is highly resistant up to a pressure of about 20,000 lb. per sq. in. and then fails suddenly.

Fig. 25 shows the average curves for all the specimens tested. The curves fall into four classes.

1. *High-Grade, Intermediate and Second-Sample Brass Special Metals.*—The first part of curve is straight up to a pressure of about 4590 lb. per sq. in., after which the compression increases much more rapidly. Strength at 10-per-cent compression, 15,500 to 17,000 lb. per sq. in.

2. *Prime Western, Second Sample, and Brass Special, First Sample.*—The first portion of curve is straight up to a pressure of about 4500 lb. per sq. in., after which the compression increases much more rapidly with the load, but not as rapidly as in the case of Class No. 1. Strength at 10-per-cent compression, 20,000 lb. per sq. in.

3. *Prime Western, First Sample.*—Curve is a straight line up to about 5000 lb. per sq. in.; the deformation then increases more rapidly, but not so rapidly as in the case of Class No. 2. Strength at 10-per-cent compression, 28,000 lb. per sq. in.

4. *Dross.*—Straight line function up to about 5000 lb. per sq. in.; then another straight line function but with a steeper slope up to a pressure of approximately 20,000 lb. per sq. in. after which the material fails rapidly.

EFFECT OF SPEED OF TESTING ON COMPRESSIVE STRENGTH.

Below are given the compressive strengths at 10-per-cent compression of three specimens of High Grade spelter, second sample, which were tested at different speeds.

	No. 1.	No. 2.	No. 3.
Speed of testing, in. per min.....	0.5 in. per min.	About 0.05 in. per min.	0.0319 in. per min.
Strength at 10-per-cent compression, lb. per sq. in.....	23 710	16 680	16 400

No. 1 tested at high speed gives a much higher strength than No. 2 or No. 3, which are nearly the same. Probably a specimen tested at even slower speed than No. 3, would not show a great reduction in compressive strength at 10-per-cent compression.

DISCUSSION.

The Chairman. VICE-PRESIDENT A. W. GIBBS (*in the chair*).—The Chair would like to ask whether this metal is used raw, or only in alloys. Of course, I except such metals as battery zincs, etc. Is there any direct use of spelter as a casting metal?

Mr. Rigg. MR. GILBERT RIGG.—In zinc castings there is a certain amount of spelter used. It is used very largely in galvanizing, in alloys, in brass, etc.

The Chairman. THE CHAIRMAN.—What I mean to ask is whether castings are made directly from zinc alone.

Mr. Rigg. MR. RIGG.—Yes, sir, they are made directly from zinc.

Mr. Price. MR. W. B. PRICE.—In regard to Mr. Rigg's statement as to the effect of cadmium on the hardness of spelter, where the lead content is relatively the same, I should like to state that some years ago we were using for certain purposes a spelter running about 0.50 per cent of cadmium, and found it necessary to anneal the spelter owing to the high cadmium content. We then obtained spelter containing no cadmium and practically the same amount of iron and lead, and found that we could use that without any annealing at all.

Mr. Karr. MR. C. P. KARR.—I should like to ask whether the size of the crystals, other things being equal, is any indication of the purity of the metal.

Mr. Rigg. MR. RIGG.—In the case of very impure metals, like a dross, the size of the crystals is usually pretty small.

Mr. Campbell. MR. WILLIAM CAMPBELL.—When one looks up the physical constants of any metal, one is immediately struck with the fact that physical properties depend entirely on the text-book to which one may have referred. The authors of this paper are to be congratulated on bringing their data before us in this form, because it is shown that such variation can be cleared up in the way they have done it. This paper has brought most clearly before us the fact that the physical properties of the metal under discussion depend not only on the chemical composition, but also to a great extent on the structure of the material. I think that is very often lost sight of in testing metals.

STUDY OF BEARING METALS AND METHODS OF TESTING.

By T. D. Lynch.

One does not have to go very far into the study of materials for use in the construction or maintenance of machinery until the question of the proper bearing material is presented. Shall it be made of solid bronze or shall it be made of a bronze or cast-iron shell lined with babbitt? If the latter, what shall the composition of the lining be and how can it be tested?

The discussion following will be confined primarily to the babbitted type of bearing with special reference to the importance of proper heat treatment in order to produce a good babbitt and further to the description of certain tests that have been made in connection with the study of the subject.

The introduction of lined bearings dates back to Sir Isaac Babbitt who first used a composition containing approximately 90 per cent of tin, the remainder being copper and antimony. This babbitt is sometimes known as "Genuine A-1", and when properly made is tough, hard, has a low melting point, good anti-frictional qualities and is more nearly fool-proof than any other babbitt in use. It has therefore become a valuable standard for the comparison of quality. However, the price of tin has become so high (approximately 50 cents per pound), that the problem of a substitute for the A-1 babbitt has become of great commercial importance; so much so that almost every conceivable formula of tin, lead, antimony, copper, zinc and nickel have been suggested and many of them tried in service as a substitute for the A-1. Some of these have met with success while others have met with very marked failure. This infinite variety of possible compositions, together with varying temperatures and hit-or-miss methods of handling the material, has produced innumerable variations in the efficiency of the product.

Both laboratory and service tests have shown that good results may be had with the lead-base as well as the tin-base babbitts, so the problem reduces itself to a study of the condi

tions necessary to produce certain anti-frictional and mechanical qualities, and of the methods of testing for them.

During recent years we have been conducting a series of tests in the laboratories and works of the Westinghouse Electric and Manufacturing Co., at East Pittsburgh, for the purpose of determining some reliable yet practical test that would indicate the essential qualities and give a check on the materials used and on the method of manufacture, by means of which we may learn *why* a certain babbitt should be used, *how* it should be treated, and *what* it will do when completed and in service.

The first test was conducted on a well-known friction testing machine, the results of which were not conclusive in that they could not be duplicated from day to day even on the same test sample. The experiences of others were then sought and among them the late Dr. C. B. Dudley was appealed to for a reliable friction test. He replied that he had tried all known laboratory tests and semblance of tests, to be convinced that only the service test could so far be relied upon.

We next turned our attention to a practical service test on motors operating under severe shop conditions. Ten motors were selected for the test. They were of varied sizes but all had cast-iron shells lined with tin-base babbitt metal. The bearings were all replaced with other bearings lined with the lead-base metal carefully and properly made. In every case the lead-base lining stood up as well and in some cases better than the tin-base lining—the severe conditions under which they were operating remaining the same.

This test was so satisfactory and apparently so conclusive that the lead-base metal was adopted for the bearings of a certain line of motors and accordingly manufacture was begun under normal shop supervision, but very soon bearing troubles were reported from the test floor. Some of the relatively few bearings which gave trouble were brittle, while others were soft and wiped out. The existence of these opposing characteristics of failure in a few bearings, in spite of the good results found in a large majority of the bearings on test as well as under normal service conditions, gave us much concern, and the difficulties encountered shattered the faith so far placed in the lead-base metal, because it was not entirely clear as to what had caused the occasional failure.

In order to determine the underlying causes for these varied characteristics a test to destruction was planned. With this object in view a test bearing was made from a lead-base metal but under careful supervision; each bearing was measured accurately, each set of measurements including five diameters equally spaced at each end and at the middle of the bearing. The bearings were then mounted in a test motor as shown in Fig. 1. The motor selected was a 15-h-p., D.C., variable-speed motor. A 265-lb. weight was mounted eccentrically on the pulley end of the shaft. The motor was run at speeds increased by easy

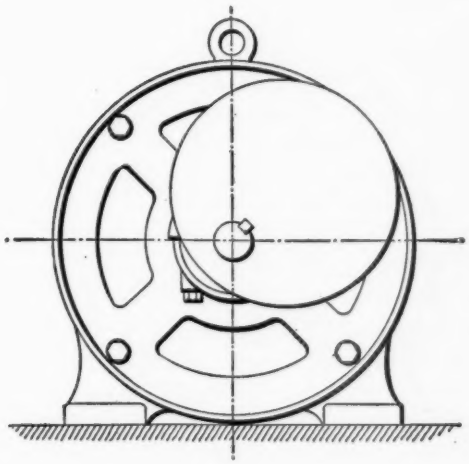
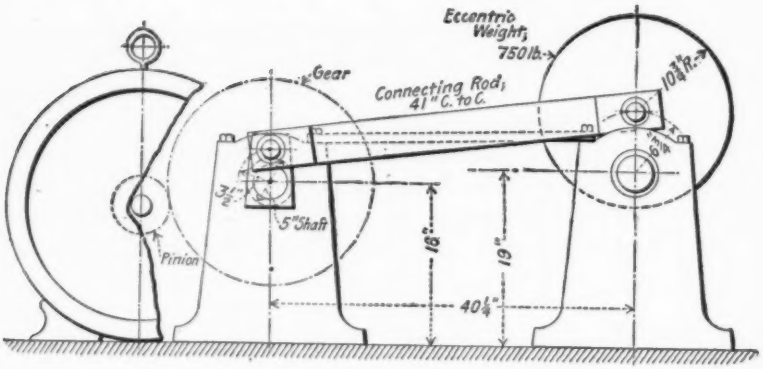


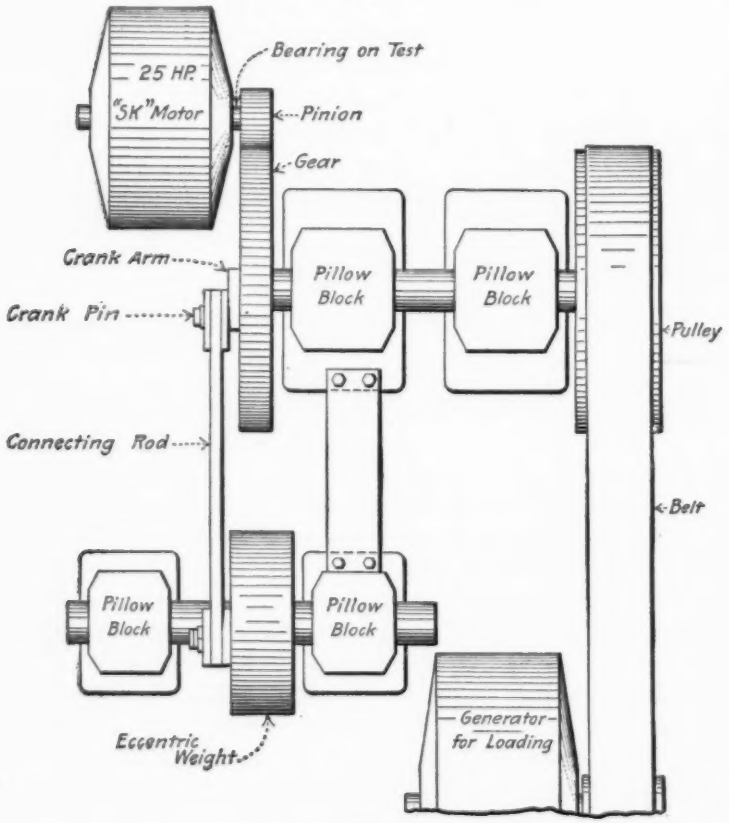
FIG. 1.

steps until the limit of the motor frame was exceeded and the frame destroyed; yet the bearing remained in good condition.

A second test was planned using the same bearing and a 25-h-p. motor arranged as shown in Fig. 2 (*a*) and (*b*). This motor was back-geared to a counter shaft to which in turn was coupled an arm driving an eccentric weighing 750 lb., thus producing a shock similar to the effect found in the operation of a rock crusher. A generator was belted to the same counter shaft in order to load the motor in the test. The motor was run light for several days with shock effect only. It was then loaded by steps until an excessive overload was reached, which


Eccentric Weight, 750 lb.
Gear
Connecting Rod, 41" C. to C.
10 3/4" R.
3 1/2"
5" Shaft
Pinion
18"
19"
40 1/4"

(a)


25 HP. "SK" Motor
Bearing on Test
Pinion
Gear
Crank Arm
Crank Pin
Connecting Rod
Pillow Block
Pillow Block
Pulley
Belt
Pillow Block
Pillow Block
Eccentric Weight
Generator for Loading

(b)

FIG. 2.

in addition to the continual shock caused by the eccentric produced a condition much more severe than is allowable even in extreme practice. Yet with all this the bearing remained in good condition and check measurements showed negligible wear.

In this connection it may be well to state that there is a distinct difference between bearing metal and bearings, because bearing troubles may be due to many causes not inherent in the metal—such as defective alignment, improper lubrication, insufficient clearance, sand in oil, abnormal belt pull, etc., all of which must be considered separately from the bearing metal itself.

No definite measure of quality could be deduced nor conclusions drawn from the above tests, therefore other tests were sought which would give a measure of comparative value. The Brinell test was next tried as follows: a 500-kg. weight on a ball 10 mm. in diameter for a period of 30 seconds was used. The sample was poured into an open steel mold 2 in. in diameter by $\frac{5}{8}$ in. deep, previously heated to about 150° C. Before making the impressions the specimens were faced off, removing just enough metal to even up the two flat surfaces. The Brinell test was then made on the bottom end of the specimen at three equally spaced points on a circle one-half the radial distance from the center. An average of the three readings was recorded as the hardness of the metal. A Brinell hardness numeral of 30 for tin-base and 23.5 for lead-base metal was found to give most excellent results, other things being normal; but this test did not reveal the whole story, since it failed to differentiate between toughness and brittleness.

A further test was found to be necessary in order to detect and study these two characteristics, so a hammer test was devised which has shown results that indicate the qualities of the babbitt more clearly and definitely than any other quick test. The test specimen if soft peens out, if brittle it breaks, while if soft and brittle it peens out and crumbles.

This test resembles the most severe service conditions with the wiping action left out and is introduced here as worthy of the most careful consideration. The many tests made have proven it to be extremely useful in giving a measure of brittle-

ness and toughness. When used in combination with the Brinell test we have no difficulty in detecting defective babbitt metals.

A series of hammer tests was inaugurated with special reference to the comparative qualities of the lead-base and the tin-base metals. These tests included a great variety of heat treatments and methods of handling the metal and their results emphasized the favorable possibilities of the lead-base metal, but also showed clearly that the temperature of both the smelt-

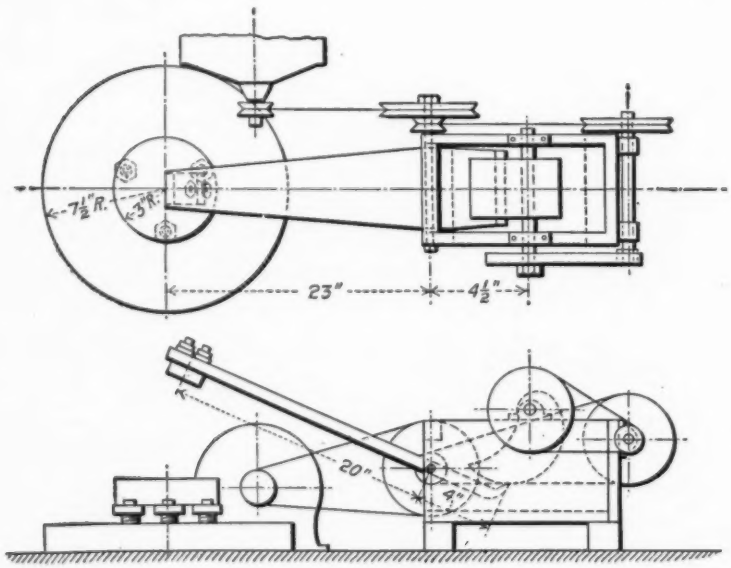


FIG. 3.

ing and pouring of the metal must be kept within narrow limits.

The samples for test were made as follows:

The metal was poured into a metal mold, producing a rough casting $1\frac{1}{4}$ in. in diameter by $\frac{5}{16}$ in.thick, which was then turned to 1 in. in diameter by $\frac{1}{4}$ in. thick. The turned sample was placed on the anvil of the testing device and the hammer set in motion. Readings were taken at frequent intervals, observing thickness of sample and number of strokes, from which curves were plotted.

Samples were taken from the kettles where the different alloys were being smelted, from stock ingots remelted in a hand ladle and from various babbitting pots. A careful record was made of all conditions that might affect later results, including the temperature and general condition of the metal, as well as the temperature of the molds into which they were poured. The results of the tests on these samples demonstrated clearly that some were hard and brittle, some soft and brittle and others soft and plastic, while still others were hard and tough. The tin-base samples showed much less variation than the lead-base although some of the very best results obtained were from the lead-base metal. These observations and tests further indicated that smelting and pouring temperatures especially of the lead-base metal were of prime importance.

The following detail study of the lead-base metal was then made on material known to be of good quality before subjecting it to different temperatures. The results are shown in Figs. 4 and 5. The samples are numbered 1 to 12.

No. 1 was poured at 320° C. Note the granular and brittle condition of the metal due to having been poured too cold.

No. 2 was poured at 700° C. Note the unstable character of this sample due to having been poured too hot.

No. 3 was heated to 700° C., allowed to become cold, then reheated to a similar temperature many times and finally reheated and poured at 460° C. This sample was also unstable due to repeated overheating, even though poured at a proper temperature.

No. 4 was heated to 550° C. and allowed to become cold, then reheated to a similar temperature many times and finally reheated to about 490° C. and poured. Note the brittleness due to repeated overheating, even though the temperature was only slightly higher than that necessary for the pouring of good bearings.

No. 5 was heated to 700° C. and cooled to 400° C. before pouring. Note the softening effect due to the single overheating.

Nos. 6 and 7 were poured at 360° C. Both show a decided improvement over No. 1 but were poured at too low a tempera-

ture to produce the proper hardness and toughness necessary for a good bearing.

No. 8 was heated quickly to 600° C. and poured at once. Note that very little damage was done by the one overheating.

No. 9 was heated similarly to 600° C. but cooled to 460° C. before pouring. Note the difference in shape of curves Nos. 8 and 9.

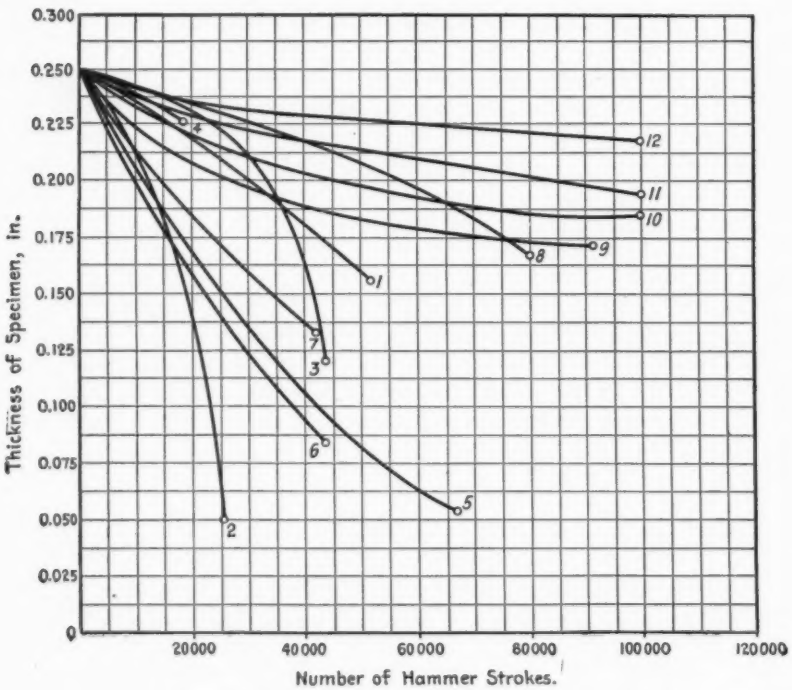


FIG. 4.—Curves showing Effect of Temperature on Babbitt Metal.

Nos. 10 and 11 were poured at 480° C. and No. 12 was poured at 460° C.; all were hard and tough giving curves characteristic of a good babbitt.

A large number of tests, not here shown, were also made on babbitts of a great variety of composition for the purpose of comparison. The tin-base-babbitt curves were practically all found to be within the limits shown by Nos. 10, 11 and 12 of Figs. 4 and 5. No babbitt tested gave better curves than those

made from the lead-base metal when carefully and properly made, thus demonstrating the possibilities of the lead-base metal.

This series of tests was so conclusive as to the importance of temperature limitations that a temperature regulator was designed and installed on each babbitting pot. These regulators were so adjusted and safeguarded as to render it impossible

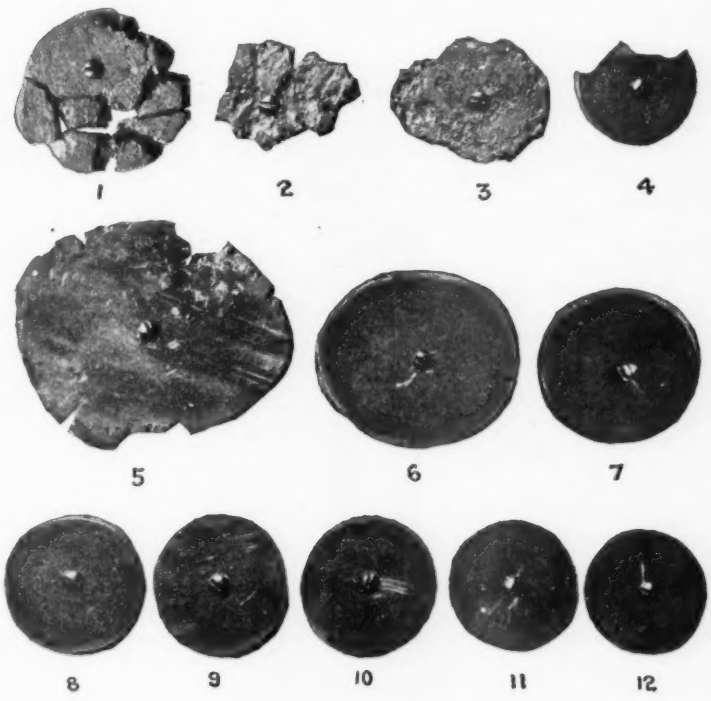


FIG. 5.

for the temperature of the babbitt in the pot to exceed a fixed limit.

It has been found to be entirely practical to automatically regulate the temperature of the metal in the pot so that the variation from a fixed point need not be more than plus or minus 10° C., and this variation is well within the range of safety for the lead-base as well as the tin-base metal.

The hammer testing device shown in Fig. 3 on which data for the curves of Fig. 4 were made proved so interesting and instructive that an improved drop-hammer was designed and built. This is shown in Fig. 6. This hammer gives a blow of $1\frac{3}{4}$ ft-lb., but since the anvil is heavy, curves similar to those of Fig. 4 are obtained with only about five per cent of the number of strokes, and with a correspondingly shorter length of time for the test than was required on the device shown in Fig. 3.



FIG. 6.

All of the more recent tests including the following have been made under the new hammer, and Figs. 7 and 8 are introduced to illustrate characteristic hammer test curves and appearance of test pieces made from five different bearing alloys under normal conditions.

These tests represent a few of a long series of tests made in connection with commercial work with special reference to the following features: raw material used, smelting and refining

in the crucible or kettle, Brinell hardness of standard samples of the ingot as poured, remelting and pouring temperatures at the babbitting pot, temperatures of the shells into which the metal is poured, Brinell tests and hammer tests taken from the babbitting pots at frequent intervals, and to a limited extent the microscopic structure of babbitt known to be good as well as that known to be defective.

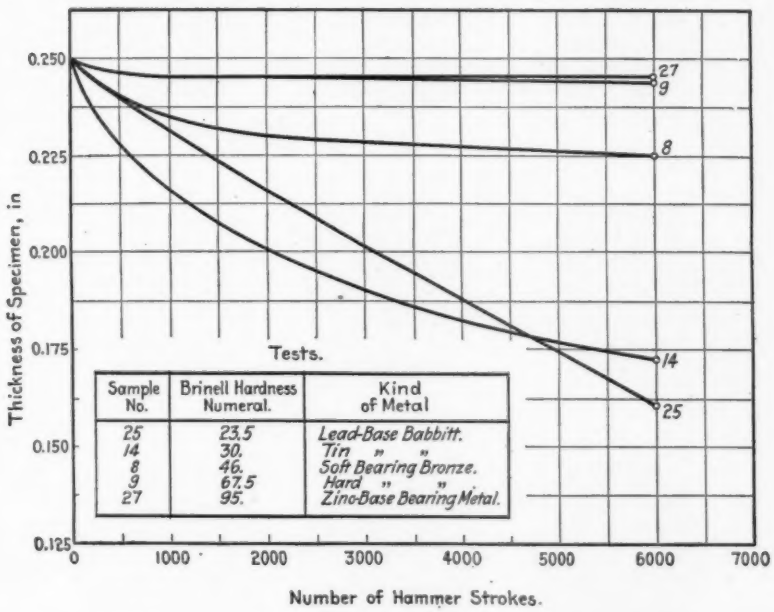


FIG. 7.—Comparative Curves of Babbitt and Bronze Bearing Metals.

CONCLUSIONS.

The conclusions drawn as a direct result of these tests, together with a large amount of service experience, may be summarized as follows:

1. The number of compositions of babbitt metals should be as few as possible, preferably one of the tin-base and one of the lead-base and each should be made the best of its class.

2. The constituent metals must be of superior grade, carefully tested and inspected, since the first requisite is a good raw material.

3. The alloying or smelting is of vital importance and must be so done that the high and low-melting-point metals may be properly alloyed far below the melting point of some of the component parts. A temperature of 500° C. and less has been found to be sufficient to obtain satisfactory alloying of babbitt

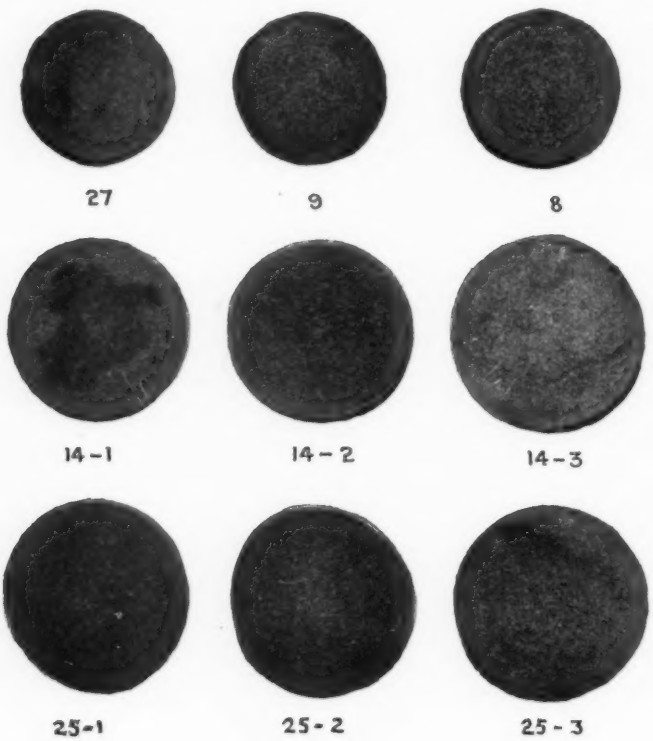


FIG. 8.

metal. The melted metal should at all times be kept covered with powdered charcoal or other protection from oxidation.

4. Pouring the babbitt too cold tends to produce a granular or coarse crystal formation and pouring it too hot tends to produce a softening effect. The lead-base babbitt is not nearly as fool-proof as the tin-base, and therefore the range of pouring temperature is more limited. However, a pouring temperature

of 460° C. (450° to 470° C.) for both lead-base and tin-base babbitts has been found to give most excellent results.

5. Heating the shell to 100° to 150° C. before the babbitt is poured into it tends to prevent blowholes and similar defects and also prevents the lining from shrinking away from the shell.

6. Babbitted bearings must not be jarred while the metal is solidifying since any disturbance at this temperature tends to enlargement of the crystals and corresponding brittleness.

7. The matrix of the lining metal should be just stiff enough to support the hard crystals. These hard crystals should be as numerous as possible and yet not lie on each other to cause brittleness.

8. A Brinell hardness of 23.5 for lead-base and 30 for tin-base babbitts has been found to give most excellent results.

These tests and suggestions are offered simply as a study to be furthered by those interested in applying babbitted bearings to their several service conditions; and while no final decision can be reached as the result of these tests, they certainly do emphasize the great importance of working closely to given compositions, and of following definite processes checked by chemical tests, Brinell tests, hammer tests, careful supervision, and finally by the court of last resort, service.

DISCUSSION.

Mr. Cowan.

MR. W. A. COWAN.—The paper presented by Mr. Lynch is extremely valuable and interesting, and the information given and the further study outlined is greatly needed in the practice of applying bearing metals.

We have had practically the same experience with friction tests as is here described, having made a series of tests on a friction testing machine designed by Mr. G. W. Thompson. From these tests we could draw no certain conclusions, owing to the many varying conditions, but expect to continue them after eliminating some of the variables.

Would it not be well to have the formulas of the metals tested given with the results reported, so that the microstructure of the alloys could be considered? The babbitts described are probably of a heterogeneous structure; the tin-base metal probably being composed of crystals of the compound CuSn, and possibly SbSn compound, in a matrix or ground mass of solid solution of tin and antimony; and the lead-base alloy having crystals either of antimony or of SbSn compound embedded in a eutectic ground mass, as described by Mr. Campbell. In relation to this structure of the alloys, the question as to whether the structure will be stable or metastable, or whether the segregation will be more or less, depends on the heat treatment—that is, the quick or slow cooling. The effect of this difference in structure on the properties of an alloy may be very great.

The further study suggested by Mr. Lynch might be made on alloys of homogeneous structure, using metals in the proportions which would give either a solid solution or a compound, or even the pseudo-homogeneous eutectic. This would show the effect of heat treatment on the size of the crystal grains, independent of the change in structure. The tests might then be extended to alloys of heterogeneous structure, wherein the microstructure can be so greatly changed by heat treatment.

Mr. MacPherran.

MR. R. S. MACPHERRAN.—I should like to ask Mr. Lynch as to the percentage of lead in that lead-base metal.

Mr. Lynch.

MR. T. D. LYNCH.—The lead-base metals used in these tests contained from 50 to 85 per cent of lead.

Mr. Capp.

MR. J. A. CAPP.—In practical use, bearings can perhaps be placed in two classes, according to the service to which they are subjected. In the ordinary type of bearing that is used in a steady running machine, there is simply friction to be contended with and the ability of the metal to withstand the dead load rotating against the bearing. The other class is that in which, in addition to friction and dead load, there is a peaning action or hammer blow. General experience tends to indicate that the tin-base metals are more apt to stand up well in bearings of the latter class, while the lead-base babbitts give excellent service in bearings of the former type. Mr. Lynch's paper indicates partly why this is so, but it has occurred to me that one reason why practical experience has shown the same thing is that the tin-base metals are relatively more nearly fool-proof. There seems to be a wider range of temperature to which the tin-base metals may safely be subjected without spoiling them, whereas the lead-base babbitt metals seem to be relatively more sensitive to temperature, and while experience has shown that lead-base metals often will stand up under peaning action, they frequently will not do so, whereas the tin-base metals will generally stand up.

Mr. Lynch's paper is very welcome, in that it shows us a means of testing out these differences, and of showing the reason for the preference based on practical experience.

The Chairman.

VICE-PRESIDENT A. W. GIBBS (*in the chair*).—The paper shows that the metals tested with certain heat treatment did not go to pieces, either by spreading or by becoming brittle and dropping out. Does it show that the metals which performed satisfactorily in the above respects are also good for carrying loads? Does it follow that such metals as Nos. 12, 11, and 10, which behaved so well under the drop, would also be good metals from the heating standpoint?

Mr. Lynch.

MR. LYNCH.—In answer to your question, Mr. Chairman, I do not know that it follows that the bearing which best resists hammer action is also a good anti-friction metal. There are so many other ways of determining anti-frictional qualities of metal, that I have left that open. We know, for example, that a certain analysis will give good anti-frictional qualities, and there is seldom trouble from that source alone.

With reference to peaning, that action is due in my opinion to stresses in excess of the elastic limit.

ESTIMATION OF FINE PARTICLES IN CEMENT BY RATE OF HYDRATION.

By H. S. Spackman.

The purpose of this paper is to bring to the attention of students of cement, in the hope of their continuing the work, a hitherto univestigated field of research which shows possibilities of developing a test more thoroughly indicative of the efficiency of grinding than the present sieving test.

The tests forming the basis of this paper were undertaken in connection with membership in Committee 30 of The International Association for Testing Materials, to which was assigned the problem of developing a method for the determination of fine flour in cement. Professor Gary, chairman of the committee, advised the members that there was no pre-determined program for the investigation, but that each member of the committee was left free to proceed independently to determine which of the two proposed methods—namely, the separation of the cement, either by air or by liquid, into portions, according to the size of the particles—would best serve the purpose, or to develop another method if he thought it desirable that both processes be abandoned and replaced by another more reliable or simple one.

It was decided, in view of the fact that the other members of the committee were studying the separation of fine particles by liquid or air, to investigate what relation, if any, existed between fineness of grinding on the one hand, and the decrease in specific gravity and increase in combined or chemically fixed water in the set cement on the other. While it was realized that such a relation, if demonstrated, would give no definite information as to the various percentages of the particles of different sizes present, it was thought that if either the decrease in specific gravity or increase in water of combination was shown to have a sufficiently constant relation to the amount of cement present in a fine enough state of sub-division to take part in the chemical reactions of setting and hardening, the purpose for

which the committee was appointed would be accomplished. It was also thought, in view of the known fact that the chemical composition and degree of burning, as well as fineness of grinding, are important factors in determining the activity of particles of cement of a given size, that the determination of the rate and extent of hydration would be a more correct index of the value of the cement than the mere determination of the percentages of particles of various sizes present, since the effect of chemical composition and burning, as well as of fine grinding, would be included in any conclusions drawn from the determination of the rate and extent of hydration, evidenced either by the content of combined water or decrease in specific gravity.

While the following tests are in no way conclusive, and are confessedly open to criticism for lack of completeness and crude-

TABLE I.

	SPECIFIC GRAVITY.
Cement before gaging	3.17
Gaged Cement:	
24 hr. in air	2.86
24 " " " 24 hr. in water	2.78
24 " " " 6 days in water	2.74
24 " " " 13 " " "	2.63
24 " " " 20 " " "	2.57
24 " " " 27 " " "	2.57

ness of the methods employed, they are sufficiently concordant to suggest, if not to prove, the existence of a more or less definite relation between the fineness of grinding on the one hand, and the decrease in specific gravity and increase in the content of water of combination of the hydrated cement on the other.

In order to ascertain in a general way the rate of hydration of a normal cement, a commercial sample which passed the Standard Specifications of this Society was made into neat briquettes. These were stored 24 hours in moist air, then submerged in water. Briquettes were taken at the several periods indicated in Table I, ground, dried to a constant weight at a temperature of 100° to 110° C., and the specific gravity determined.

These tests, as might be expected, showed upon first hardening a marked decrease in specific gravity and a gradual decrease

as hydration proceeded, up to the 21-day period, after which no decrease in specific gravity was noted, indicating for this particular sample the practical completion of the initial hydration prior to the 21-day period.

In order to ascertain whether the maximum hydration took place when the cement was in the form of a mortar, a sample of the same cement was placed in a test tube with water and agitated for 28 days. This, when tested in the same manner, gave a specific gravity of 2.47 and a loss on ignition of 15.52 per cent, indicating probably the maximum hydration attainable at 28 days under ordinary temperature conditions.

In order to determine the effect of the size of grains on the rate of hydration, another cement having a specific gravity

TABLE II.

Cement.	Specific Gravity of Hydrated Cement.	Loss on Ignition, per cent.		Increased Loss by Hydration, per cent.
		Before Hydration.	After Hydration.	
As received after hydration.....	2.94	1.70	5.22	3.52
Passing the 100 and retained on the 200-mesh sieve.....	3.12	0.65	1.45	0.80
Passing the 200-mesh sieve.....	2.84	1.95	6.17	4.22

of 3.17 and loss on ignition of 1.70 per cent was tested. Twenty-gram charges of the cement as received, of the portion of the cement passing the 100-mesh and retained on the 200-mesh sieve, and of the portion that passed the 200-mesh sieve, were placed in test tubes with 50 cc. of water, and continuously agitated for a period of 24 hours, then dried to constant weight at 100° to 110° C., after which the specific gravity and loss on ignition were determined on the three samples. The results are given in Table II.

In order to determine whether exposure to steam at atmospheric pressure would give at short periods hydration approximating that after a longer exposure in water, the same cement in the condition it was received, the portion that passed the 200-mesh sieve, the portion passing the 100-mesh and retained on the 200-mesh sieve, and the cement after grinding in a lab-

oratory ball mill for 1, 2 and 3 hours respectively, were made into neat mortar, allowed to stand in moist air for 24 hours, then subjected to steam at atmospheric pressure for 24 hours. The results obtained are given in Table III.

TABLE III.

Cement.	Fineness, per cent passing sieves.		Specific Gravity of Hydrated Cement.	Loss on Ignition, per cent.		Increased Loss by Hydration, per cent.
	No. 100.	No. 200.		Before Hydration.	After Hydration.	
As received.....	95.6	77.8	2.66	1.70	8.58	6.88
Ground 1 hr.....	99.8	91.0	2.60	1.70	9.41	7.71
Ground 2 hr.....	100.0	97.0	2.59	1.70	9.33	7.63
Ground 3 hr.....	100.0	99.0	2.58	1.70	10.93	9.23
Passing 100 and retained on the 200..	100.0	00.0	3.03	0.65	1.60	0.95
Passing the 200 sieve	100.0	100.0	2.63	1.95	10.17	8.22

In order to determine whether subjecting the cement to the action of steam at high pressures and temperatures would show a further decrease in specific gravity and increase in water of combination, another cement was made into briquettes. A part of these were subjected, after exposure, to moist air for 24 hours and to a steam pressure of 20 atmospheres in an autoclave

TABLE IV.

Cement.	Specific Gravity.	Loss on Ignition, per cent.	Content of Carbon Dioxide, per cent.	Content of Combined Water, per cent.
Before hydration.....	3.16	0.50	0.40	0.10
Hydrated in moist air for 24 hr....	2.74	6.90	1.25	5.65
After hydration in air and exposed to steam pressure of 20 atmospheres for 2 hr.....	2.63	9.60	1.35	8.25

for 2 hours. Table IV shows the specific gravity, loss on ignition, and content of carbon dioxide and combined water, of briquettes exposed to moisture in the ordinary way and to high steam pressure in the autoclave.

In the absence of any known data showing the specific gravity of a completely hydrated cement, a sample of another brand of cement was taken as received, made into a slurry with 60 per cent of water, placed in a laboratory ball mill, ground for 8 hours and allowed to stand over night. This cement, on examination next morning, was found to be partially set. Water to the amount of 60 per cent of the original weight of the cement was added, grinding continued for 8 hours, and a sample taken for analysis. The cement was allowed to stand over night as before. The next morning, while not set, it was found to be too thick to allow of continuing the grinding; and a third addition of water to the amount of 60 per cent of the original weight of the cement was added, making a total of 180 per cent

TABLE V.

Cement.	Specific Gravity.	Loss on Ignition, per cent.	Content of Carbon Dioxide, per cent.	Content of Combined Water, per cent.
Before hydration	3.12	1.50	1.20	0.30
After 2 days grinding	2.27	15.50	2.60	12.90
After 3 days grinding	2.27	16.90	2.50	14.40
After 5 days grinding	2.27	18.05	2.50	15.85

of water necessary to make the mixture sufficiently fluid to grind properly. Samples were taken at the expiration of the third day's grinding and at the expiration of the fifth day's grinding. After drying to constant weight at 100° to 110° C., the specific gravity of these samples was determined and analysis made for carbon dioxide and combined water. The results are given in Table V, and indicate a possible specific gravity of completely hydrated cement below 2.3 and a content of chemically combined water of above 15 per cent. It is doubtful whether so great a hydration ever occurs in practice, even after long exposure to water, although the individual particles may have even lower specific gravity.

While the above tests and others made in our laboratory show that a relation exists between fineness of grinding and the rate and extent of hydration of Portland cements, it remains

to be determined whether this relation is sufficiently definite to admit of its forming a basis for the development of a test which will replace the use of sieves in the commercial laboratory.

We regret that we were unable to carry out our intention of repeating these tests, which were made over a year ago, a sufficient number of times to determine whether the phenomenon of hydration was sufficiently positive to prevent the results obtained being markedly affected by unavoidable variations in the conditions under which the test was made, and also to ascertain whether it was possible for different operators working on duplicate samples to check each other.

We had also hoped, by working on synthetic mixtures of cement containing known quantities of particles of different sizes, to develop whether any definite relation existed between the content of particles below a certain size and the extent of hydration; also to find an explanation for the anomaly shown by these tests, of the cement being able after hydration had proceeded to a certain point to fix additional water without a corresponding reduction in specific gravity being apparent; also to determine the changes in specific gravity and combined water of cement mortars during long periods of storage under water.

[For discussion of this paper, see pp. 737-739.—ED.]

THERMAL ACTIVITIES OF PORTLAND CEMENT DURING THE PERIOD OF SETTING.

By Louis N. Beals, Jr.

A characteristic property of cement is the heat liberated during the period of setting. Plotting the time intervals after mixing as one coordinate, and the heat evolved during this period as the other, curves are obtained, unique for each sample, but falling into several classes within which close relationships exist. The possibility of thus determining the normal characteristics of a sample, later checking these determinations by the regular 7 and 28-day tests, persuaded Mr. Mont Schuyler, in charge of the St. Louis Testing Laboratory, to have a series of tests of this nature made by the writer, after Mr. A. S. Cushman had demonstrated the interest of the subject in a paper recently presented before the Eighth International Congress of Applied Chemistry, on the heat evolved by cement during the period of setting.

The initial experiments were made in an apparatus consisting of a can to hold a mix containing 900 g. of cement plus 25 per cent of water. This can was inclosed in a larger one, with a paper insulation between the cans. The curves obtained with this apparatus are shown in Fig. 1.

The exaggerated vertical scale of Fig. 1 does not reveal, as clearly as did the original graphs, the characteristic differences in the rate of temperature rise, between one brand and another. These differences are quite characteristic and comparatively consistent for each brand. The differential curves for two of the brands graphed in the first figure are shown in Fig. 5. Referring back to Fig. 1, it will be seen that the total heat evolved was very closely the same for these two samples, notwithstanding the vast difference in the rates of evolution shown by this figure.

To discover whether there was any parallelism between the thermal characteristics and the usually determined characteristics of a cement, the curves of Fig. 6 were drawn. These curves

show graphically the properties of some of the cements whose thermal peculiarities are given in Fig. 1. The curves, showing

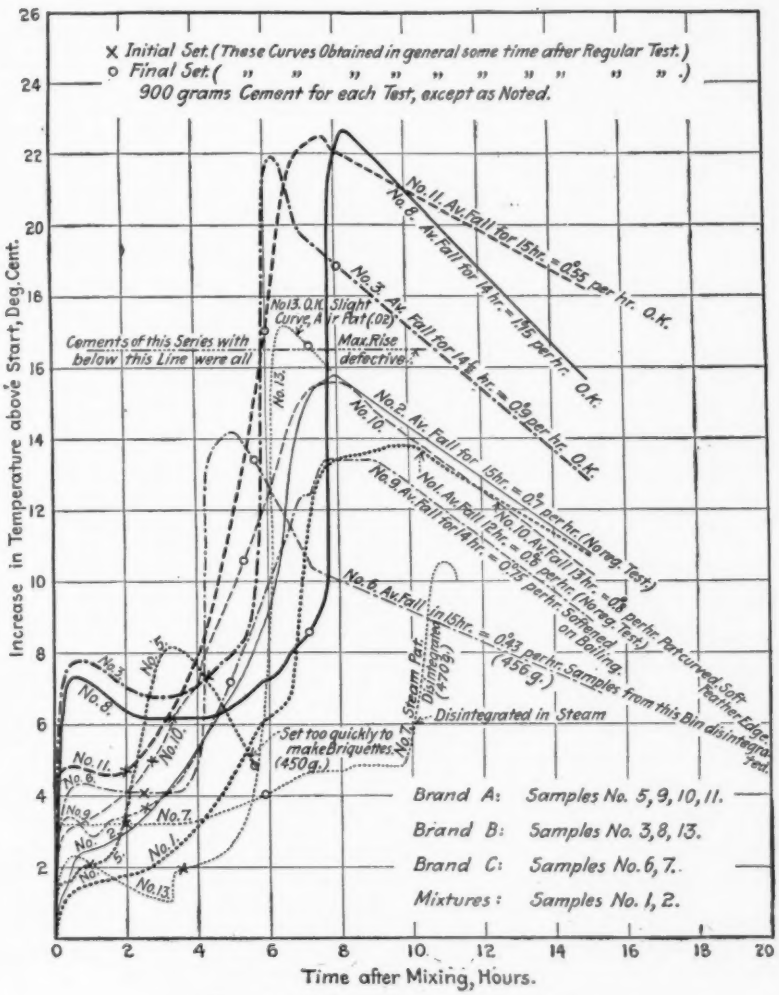


FIG. 1.—Tests with First Apparatus.

the time of maximum rise and the tensile strength of the 7-day neat briquettes, display a parallel trend and may indicate some relation. It was also noted that if the maximum heat evolved

fell below a certain amount the soundness became questionable. These results are shown in heavy dashes in the figure. Owing to the errors introduced by radiation, this line of investigation was pursued no further at the time, but data obtained with the present and more perfect apparatus are emphasizing the relationships indicated above. It was noted, however, that when unsound cement became sound by aging, the heat evolved was not increased, so far as could be roughly determined.

Even with the best possible insulation, the importance of the radiation losses during the long period of setting, was emphasized by the preliminary tests. The apparatus was therefore modified by surrounding the can with a cylinder of asbestos steam pipe covering 1 in. thick, with covers and bottom of the same material. This system was then inserted in an outer case similarly constructed and large enough to leave an air space of about $1\frac{1}{2}$ in. between the two cylinders. It was intended also to take readings of the temperature of this air space and derive radiation corrections. The heat capacity of the inner insulating cylinder, however, made the observations valueless.

Fig. 2 shows some of the curves obtained with this apparatus. They are all made on the same brand of cement, except No. 11, which is inserted for comparison of the two sets of apparatus. The comparative uniformity of the slope of these curves for one brand is apparent.

To obviate the undesirable heat capacity of the second apparatus, a vacuum bottle, with its low radiation factor and small heat capacity, was suggested. The cement paste was inclosed in a test tube, which was then inserted in water in the vacuum bottle, the protecting outer case covered with asbestos paper and a sensitive thermometer inserted through the cork. The water equivalents of the cement paste when hardened, of the test tube and vacuum bottle, corks, etc., were determined, and the observed rises reduced to calories per gram of dry cement. The bottle was rolled thoroughly to equalize the temperature before each reading of the thermometer.

Several of these curves are shown in Fig. 3. Even with the low heat loss of the vacuum bottle the radiation correction is very important, as will be seen by this figure, in which many tests were run on single samples, under very varying external

temperatures. These varying temperatures caused great differences in the curves.

To cover a point raised by Mr. Cushman, that unkneaded

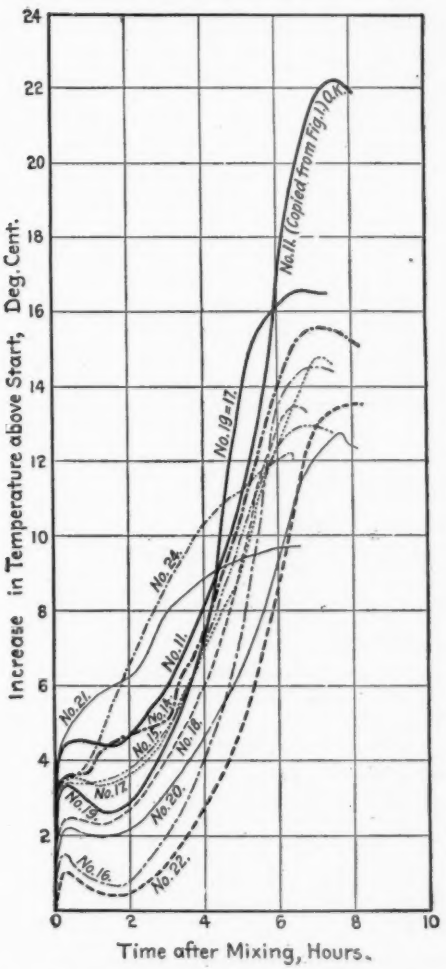


FIG. 2.—Brand A; Tests with Second Apparatus.

cement did not produce a rise of temperature, the experiment recorded in Fig. 4 was performed. In this instance the cement was added to water in a beaker, stirred thoroughly and then

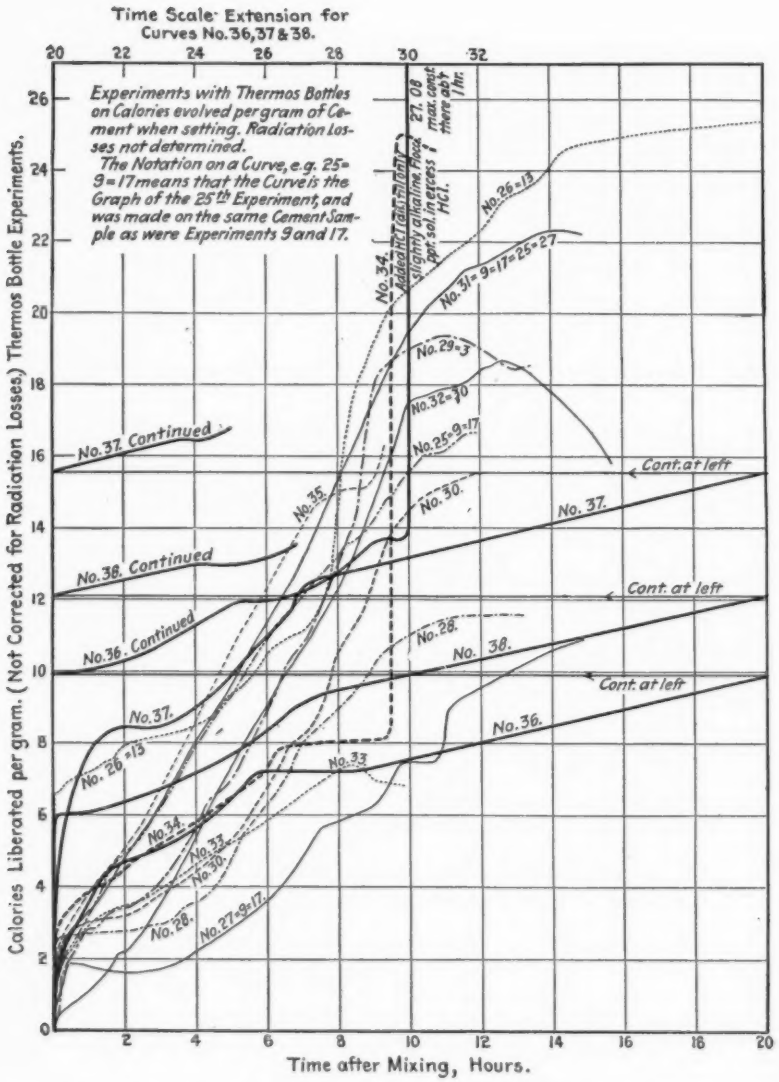


FIG. 3.—Tests with Thermos Bottle (No Radiation Correction)

poured into the vacuum bottle. It will be seen that the curve is quite concordant with curves of kneaded cement previously shown. Later experiments showed that the cement and water

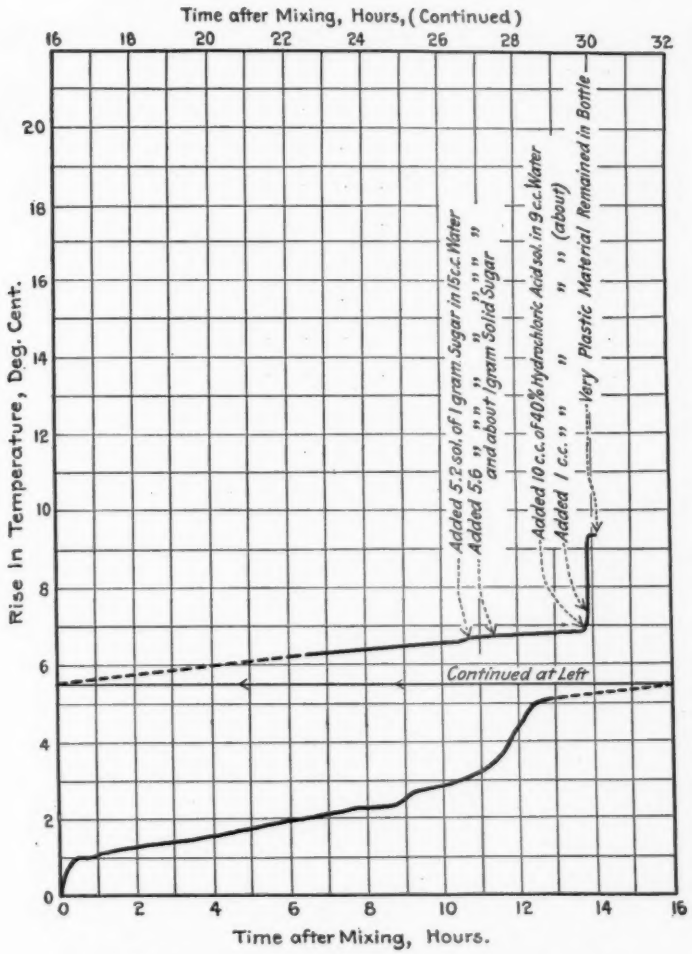


FIG. 4.—Unkneaded Cement (in Thermos Bottle).

could be inserted separately with identical results. (The additions of acids, etc., at the end were for a purpose later discussed.)

The radiation correction having been shown by the curves of Fig. 3 to be absolutely essential, even with a vacuum bottle, a machine was designed to hold six of these bottles in a revolving cylindrical case, with axes at 45 deg. to the axis of revolution, thus slowly stirring the materials in the bottles from top to bottom of the bottles, as well as circumferentially.

Pending the construction of this apparatus, a crude machine,

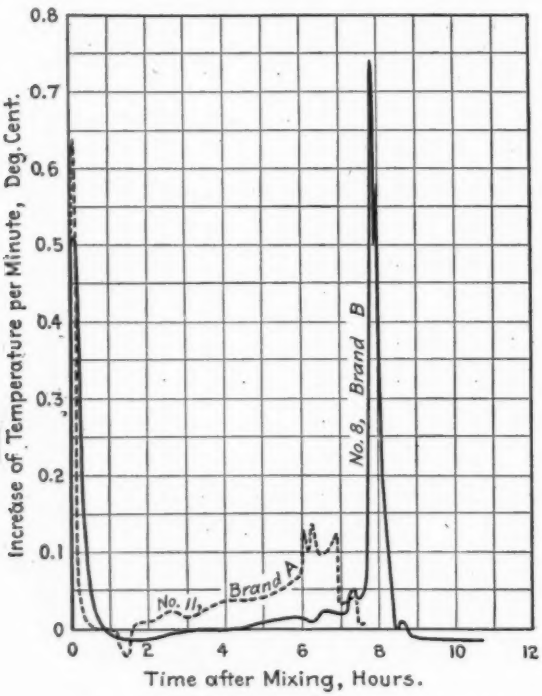


FIG. 5.—Typical Temperature Increments.

shown in Fig. 9, was constructed by the writer. The vacuum bottle, held rigidly in a cage, sets inside of a jacket can with removable top. A thermometer passes through a water-tight rubber cork in the bottle, then through a similar cork in a tubulure in the can cover. Through another tubulure a thermometer extends into the jacket water surrounding the bottle. The can is then rigidly connected at an angle of about

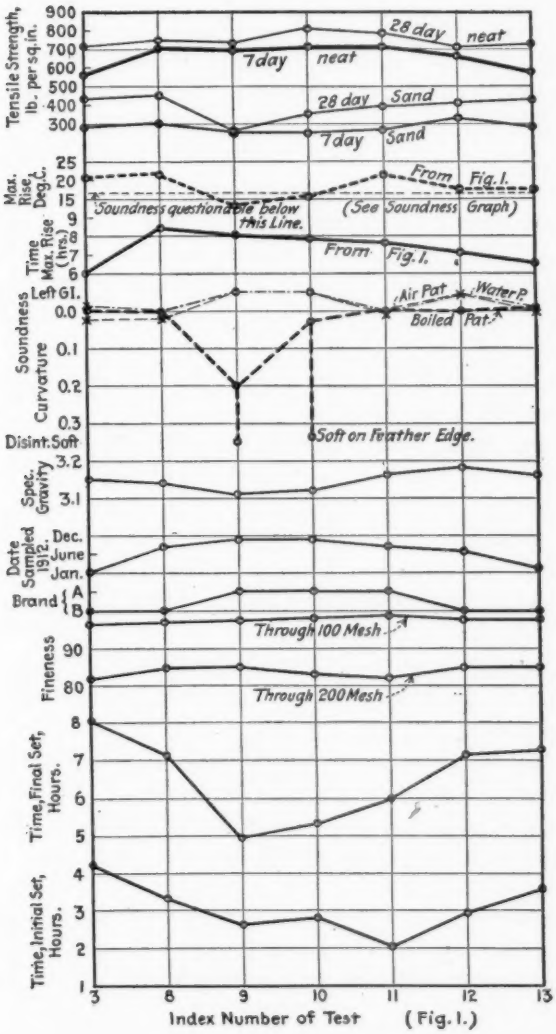


FIG. 6.—Comparative Properties.

45 deg. to a shaft of the apparatus and slowly turned by a small motor, as shown.

The revolution of the apparatus thoroughly agitates the material in the bottle and prevents its sticking to the bottle. This motion also stirs the jacket water. Later experiment has shown that the 45-deg. angle may be dispensed with and the bottle simply revolved on its axis without the charge sticking. This permitted placing the cement directly in the bottle with the desired amount of water, omitting the test tubes.

Mr. R. Hospes, under the direction of Mr. Schuyler, has been continuing the experiments in this apparatus. Very concordant results are being obtained and the points plotted all lie on quite smooth curves. Two hundred and fifty grams of dry cement are poured into 300 g. of water in the bottle, and the apparatus is stopped at intervals to allow the thermometer to be read. The radiation corrections were found by running a blank test in the apparatus, and they include any heat due to friction and stirring.

Fig. 7 shows the graphs of these experiments. It will be seen that if the radiation is taken into account the evolution of heat is discovered to continue over a period of more than 100 hours. The derivative of these curves, with respect to time in minutes after mixing, gives the heat being evolved at any given time. This is shown by curve IV for sample I. There is a sudden evolution at mixing, then a sharp minimum, probably close to the time of initial set, followed by a longer maximum which probably marks a more intrinsic property of the cement than the conventional final set. Another minimum and maximum follow, the significance of which may be developed on further investigation.

A second run on the same cement was made, as shown by curve II. It is evidently a remarkably close check with curve I, indicating that the results may be duplicated whenever desired, and much more closely than some of the usual tests. The difference at any point is but a fraction of a calorie per gram.

The use of dry cement is much more convenient and experiments are more easily duplicated than when kneaded cement is used, for some of the initial heat is lost in kneading. To determine whether kneading was essential to properly characterize

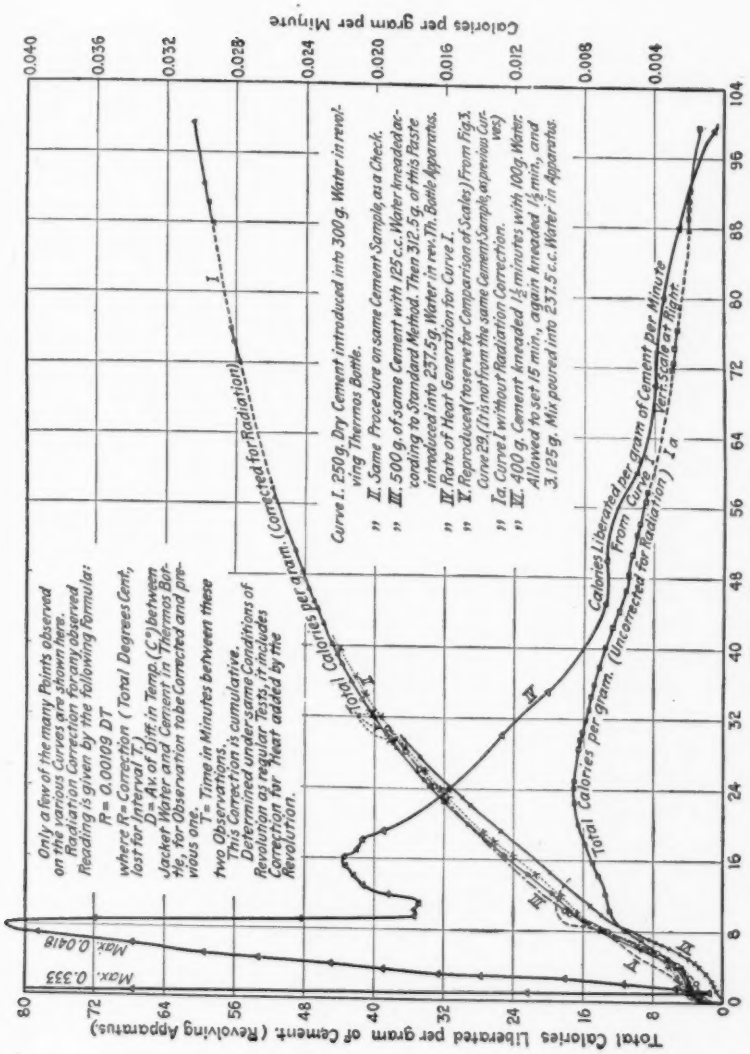


FIG. 7.—Brand C in Final Apparatus (With Radiation Correction).

the cement, a test (curve III) was made on kneaded cement. There is a slight lag in the rise at the start but by the time of the maximum the curve had practically merged with the curves I and II. This is important, as it shows that the use of dry cement, unkneaded, is entirely permissible.

To give a general idea of the relation of scales, curve V is copied from Fig. 3 on this sheet.

Desiring to know the effect of kneading cement, allowing it to lie until it stiffened slightly, then rekneading it, curve VI was run. It betrays the general characteristics of the unkneaded and kneaded but immediately tested cement, with a practically constant difference during the initial period, due to the heat lost while standing between the two kneadings; although beyond the break in the curve at nine hours, it shows a steeper subsequent rise than the other curves. The indications are that it would have reached or possibly passed them, had the test been longer continued.

A test run on some brand "A" cement of normal characteristics, but lower tensile strength, gave a curve showing the long rise of the one shown in Fig. 7, but the initial slope was less, and at 50 hours there had been 12 calories per gram less evolved. If the strength depends on the coagulation of the colloids, and this coagulation is proportional to the heat evolved, there would appear to be a direct connection between the total heat evolved and the strength. This is being investigated at the time of writing.

It is hoped, by collecting a large number of tests along the final lines above, to settle conclusively the question whether the properties of the cement may be approximately determined from such heat curves. The part of interest would be that part up to and somewhat beyond the maximum rate of heat evolution. The indications are that this method will yield data more characteristic of the cement than the usual tests, whose results, furthermore, depend so intimately upon the personality of the man making the tests.

In this connection the following quotation from "The Chemistry and Testing of Cement," Mr. C. H. Desch, p. 152, is of considerable interest:

"The thermal method promises to yield very interesting results when further perfected. The readings, with different quantities of cement, differ considerably, mainly on account of the low conductivity of the material, and hence it has not been widely adopted, but, after being standardized, it may probably come into more general use.

"Very careful precautions must be taken to minimize the loss of heat by the mass, especially in the use of slow-setting cements, as small variations of temperature may be entirely masked by the effect of radiation and conduction of heat to the surroundings. When special arrangements are made to avoid this error, the curves shown in Fig. 12 become somewhat modified, the fall of temperature after the initial set disappearing, so that the curve indicates a progressive rise in temperature, which is rapid at first, then slow or stationary, and then, when the further reaction sets in, again very rapid. The results obtained by the thermal method are therefore dependent in a much greater degree on the quantity of material used for a test than are those obtained by a mechanical or indentation method, and it is for this reason that several investigators, after a trial of the thermal test, have abandoned its use."

By abandoning the effort made by Gary to prevent heat losses, and simply correcting them, as in ordinary calorimeter work, the process becomes much more definite and feasible.

In a previous paragraph reference was made to the possibility of a relation between the heat evolved in the setting of cement and the strength of the latter. As some colloids are coagulated by acids, at the close of the test graphed in curve No. 36 of Fig. 3, some hydrochloric acid was added to reduce the alkalinity, and the resulting heat evolution, which is pronounced, observed. Similarly with the curve of Fig. 4. As this acid also acts on cement, however, an attempt was made to determine whether the colloid was first coagulated, followed by a slower colloidization of the still solid cement. Fig. 8 records the trial of varied and repeated additions of acid to equal portions of a very thin cement grout (curves I and II), comparison being made with the same volume of the decanted clear liquid (curve III) from the grout and with an equivalent amount of dry cement. The acid in each case was diluted with an amount of water which would bring the total liquid in the apparatus up to the same volume as in the previous experiments. The coordinates are in total degrees of rise against time with no radiation corrections. They demonstrate the impossibility of a decisive deduction based on the action of this particular acid.

The experiment will be repeated with some coagulating salt having no action on uncolloidalized cement. This salt will be added at different intervals after the mixing of the cement with water, in order to observe the progress of the colloidalizing action.

It seems a reasonable hypothesis to assume that the strength

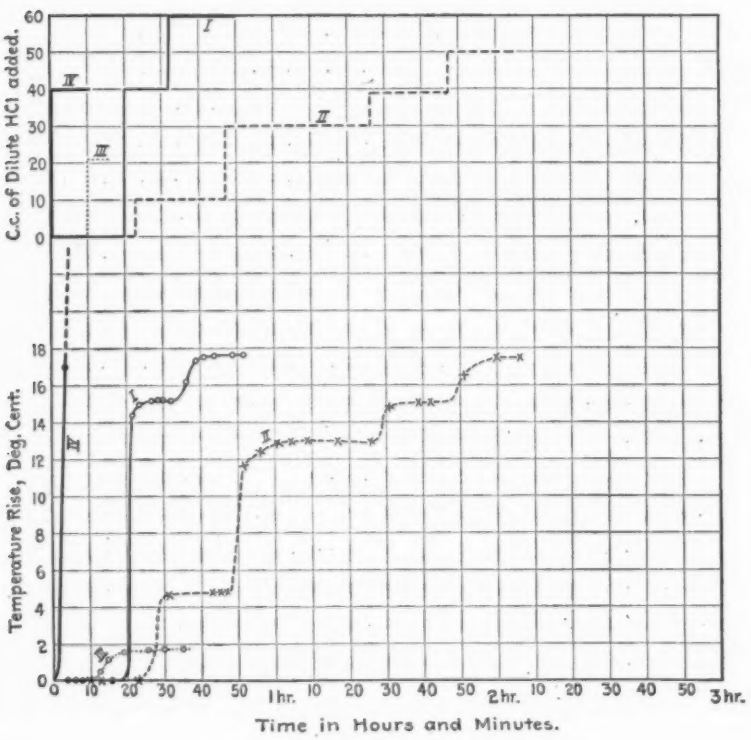
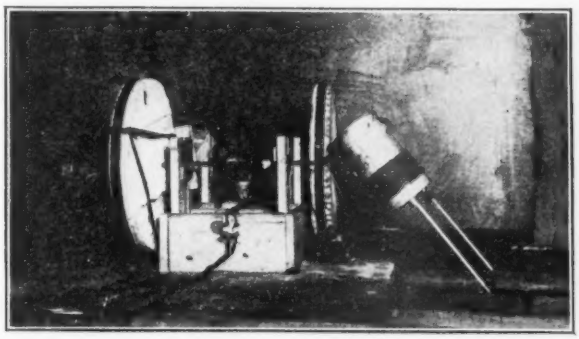


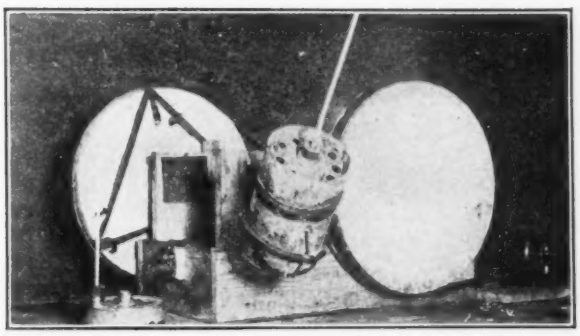
FIG. 8.—Heat Evolved on Adding Acid.

of hardened cement is due to the cohesive ability of the coagulated colloid to hold crystals, uncolloidalized bodies, etc., firmly together. The microscopic investigation of set cement mentioned by Desch has demonstrated that colloids constitute the matrix of the hardened material. Furthermore, the action of setting, etc., is very analogous to the behavior of all colloids. There is a first period, during which the colloid is formed, then

at the end of a certain interval the colloid begins spontaneously to coagulate. The coagulation of a colloid is always accompanied by a considerable evolution of heat. These phenomena are all paralleled by the action of cement. In view of the predominance of colloids in the hardened material, it should be to



(*a*)



(*b*)

FIG. 9.

the properties of colloids that we should look for explanation of the hardening action, rather than to those of crystals. Interlacing crystals give but a weak bond whereas the commercial applications of glue, the typical colloid, and of glass, as another example, all demonstrate the relatively great strength of the solid collodial state of aggregation.

Mention is also made of the fact that silicic acid is coagulated in a few minutes by a solution containing 1/10000 part of alkaline or earthy carbonate. This has a very active interest in connection with cement by showing the extremely minute quantity of a detrimental substance required to influence strongly the action of a colloid. Colloidal alumina, for instance, is coagulated by a scarcely appreciable trace of sulphate of potash and other salts. Zsigmondy[1] also demonstrates another property of colloids, that they may be protected from coagulation by small amounts of other colloids, etc. The marked influence of minute quantities of certain substances on the behavior of colloids possibly indicates that the causes for deficient cement may better be examined in the action of small amounts of impurities rather than in variation of the proximate constitution or the manufacture of the cement itself. It is reasonable to suppose, if such deleterious impurities are at all frequent of occurrence, that the development of the manufacture may have led to a procedure which produces a protecting substance which will neutralize ordinary adverse impurities, but not others less frequently encountered. It may be that very small proportions of these latter may account for inexplicable irregularities in cement.

Another striking feature of some colloids is the strength they develop when coagulating. For instance, isinglass dried on glass will tear up particles therefrom; colloidal tungstic acid may do the same. Glass itself is also a colloid possessing great strength, which is masked by its brittleness. The use of glue in the arts depends upon its strength on drying. Desch shows that it is to strength of this character, rather than to the much more feeble resistance of interlaced crystals, that the strength of cement must be ascribed. The gain in strength of cement in one day, therefore, is quite analogous to the behavior of many other colloids.

Zsigmondy[2] says: "A rise in temperature of 1°.1 C. was observed during the formation of the 5-per-cent jelly (of silicic acid)."

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[1] "Colloids and the Ultramicroscope," p. 79.
[2] *Ibid.*, p. 49.

This would be roughly in the neighborhood of twenty calories per gram, quite of the order of heat evolution observed in cement when no radiation correction was made. The heat evolution by colloidal silver, 250.98 to 126.73 calories per gram in dilute or concentrated solution respectively, is also noted. Hence the heat of coagulation of the colloid may be amply sufficient to explain the observed rise of temperature.

The following extracts from Zsigmondy[1] are relevant to this phase of the subject. Speaking of the coagulation of the colloids, he says of silicic acid, which he takes as a typical colloid:

"The solution of hydrated silicic acid, for instance, is easily obtained in a state of purity, but it cannot be preserved. It may remain fluid for days or weeks in a sealed tube, but is seen to gelatinize and become insoluble at last; nor does the change of this colloid appear to stop at that point. For the mineral forms of silicic acid deposited from water, such as flint, are often found to have passed, during the geological ages of their existence, from the vitreous or colloidal, into the crystalline condition. . . .

"A dominating quality of colloids is the tendency of their particles to adhere, aggregate and contract. This idio attraction is obvious in the gradual thickening of the liquid, etc. In the jelly itself (speaking of silicic acid) the specific contraction . . . still proceeds, causing separation of water . . . and ending in the production of a hard strong mass, of vitreous structure, which may be anhydrous, or nearly so, when the water is allowed to escape by evaporation."

The following analogies support or accord with the working hypothesis that the properties of cement are those dependent upon the nature of colloids in general.

The clinker produced by semi-fusion is largely colloidal. The cement finally coagulates, after a period of solution, like a colloid. The heat accompanying this may be developed by the coagulation, though the possiblity that crystallization plays a part must be admitted.

The hardened cement is largely composed of colloidal matrix as shown by the microscope. The strength of the product is in accord with what is known of other colloids and not with that of interlaced crystalline masses. Most colloids become crystalline only after long periods and not within a day or two, so that the strength of the colloidal cement is hardly to be expected to develop from a change into the crystalline form.

[1] "Colloids and the Ultramicroscope," p. 79.

If the setting of cement be a coagulation, then the analogy with other colloids would lead to the necessity for investigation of the effects of comparatively small quantities of impurities; for example, loam in sand, sugar, etc.

SUMMARY.

1. The evolution of heat following the tempering of Portland cement has been recognized for some time as being a unique and perhaps definitive characteristic of this material.

2. Study along this line has not been rigorously prosecuted in the past due to the difficulty of preventing heat losses. The relatively slight amount of heat evolved together with the length of time during which evolution takes place, vitiated most experimentation.

3. The use of a vacuum bottle of the familiar type, and the application of radiation corrections in place of attempting to eliminate heat losses, has produced an apparatus by means of which close quantitative results may be obtained.

4. The peculiarities of the curves obtained by plotting calories against time, seem to indicate that the time of set and tensile strength are due to the colloidal nature of cement. This is seemingly supported by references to the well-known characteristics of colloids.

[For discussion of this paper, see pp. 737-739.—ED.]

JOINT DISCUSSION.[1]

MR. WATSON VREDENBURGH, JR.—I wish to ask Mr. Spackman if the briquette passed the steaming test, and as to its tensile strength. **Mr.Vredenburgh.**

MR. H. S. SPACKMAN.—The cement passed the standard boiling test and was also exposed in the autoclave. I do not remember the strength of the briquette, but I know it showed a marked gain. **Mr. Spackman.**

MR. R. J. WIG.—It may be of interest to know that the Bureau of Standards has developed an analyzer for analyzing cements of any degree of fineness which will give results as accurately as our standard sieves, both of a sieve size and of any smaller size, that is, with a variation not exceeding 1 per cent for separate determinations. An apparatus has also been developed for separating the fine material in quantity, not quite so accurately as the analyzer but accurate enough to study the value of the various-size particles. **Mr. Wig.**

MR. SPACKMAN.—I wish to express the thought that even though we have accurate apparatus for air separation, or separation by liquid, which will enable us to determine the fineness of grinding and the different percentages of flour which are so fine as to be beyond measurement by the ordinary sieve, that does not give us a real indication of the activity of cement. The purpose of the sieving test is not solely to inform us of the amount of fine flour in the cement. We have assumed generally that the finer the cement was ground, the more active it would be, and have adopted the fineness test as indicative of activity; but other qualities beside fineness affect activity. Now, a test based on the rate of hydration, whether that is measured by the decrease in specific gravity, or by the increase in temperature and the rate at which the heat is evolved, or by the determination of the amount of water fixed, will include the other factors which contribute to the activity of the cement. **Mr. Spackman.**

[1] Joint discussion of the two preceding papers by Mr. H. S. Spackman and Mr. Louis N. Beals, Jr.

Mr. Spackman. I also wish to anticipate possibly what Mr. Bates is going to say, and express my thought that we cannot wait to find out just how cement hydrates and what its constitution is. That problem has been studied for years. The German Government some years ago offered a prize for its solution and then continued the competition, but I do not think any papers have been submitted. The problem of how cement hydrates is as far from solution, unless Mr. Bates will throw some light on it, as it was twenty years ago. Therefore I do not think we can afford to wait if, accepting that the strength of cement is due to the rate of hydration, no matter how it is caused, it can be shown that that rate of hydration bears some direct relation to the strength developed. I think there is a possibility of working out a commercial test along these lines.

Mr. Bates. MR. P. H. BATES.—The matter of hydration of cement is so complex that, when we take several different conditions, as Mr. Spackman used in his experiments and those which Mr. Beals used in his, and try to make comparisons, we immediately get into difficulties. Mr. Beals used about equal parts of water and cement. Under these conditions he obtained a hydration which is decidedly crystalline, and which is entirely different from that which we obtain in the normal hydration of cement or concrete where the proportion of water to cement is about 5 to 1 or less. In this latter condition the hydration tends toward the formation of minute crystals, and in some cases the "state" which is referred to as colloidal.

Owing to the not-completely-understood colloidal state of matter and what colloids are in general, it would be better that this term be used somewhat carefully. Thus we find in Mr. Beals' paper that cement clinker is spoken of as colloidal. This is entirely erroneous, as under a magnification of only 225 diameters, clinker will show crystals covering a quarter of a square inch. Even in the hydration of concrete, it is quite possible to observe, after a period of six months, crystals plainly visible to the eye. Moreover, under small magnification particles may appear colloidal, whereas under larger magnification they are distinctly crystalline. Mr. Beals states, "If the setting of cement be a coagulation, then the analogy with other colloids would lead to the necessity of the investigation of the effect of

comparatively small quantities of impurities, for example: loam in sand, sugar, etc." The effect of small quantities of materials on the setting of cement has been investigated by Rohland, the German physical chemist. As the result of his investigation, he concludes that the setting of cement is a catalytic action, the catalyzer being the soda and potash which are always present in very small quantities in the cement. The effect of these two materials, when present in small quantities, has been known for sometime, it having been shown that 0.10 per cent of carbonate of soda will in some cases make a cement have a flash set which ordinarily would set in several hours. The observations of Rohland are interesting but are not sufficiently extensive to be generally accepted, any more so than should the hydration of cement be considered entirely a matter of colloids. **Mr. Bates.**

More should be known in regard to the constitution of cement. If we knew what it is, we would be better able to say what happens when water is added to it. It would seem that the Germans have come to this conclusion also, for at the last meeting of the German Cement Manufacturers' Association, the papers which caused most discussion were those that related to the question, "What is cement?" These German papers are particularly interesting, and are well illustrated with sections of cement clinker. These illustrations in every case show very large crystals, and no material which can be considered a colloid.

MR. R. W. LESLEY.—Referring to what Mr. Bates has just stated as to potash and soda, Henry Reed, probably the first English authority on Portland cement, described in one of his earliest books the use of either potash or soda in cement slurry. The material was added in a machine used to make the bricks that went into the kiln. It was certainly used and regarded as a very practical thing by the cement manufacturers. **Mr. Lesley.**

MR. W. K. HATT.—There is a curious analogy between the behavior of wood and of concrete. We are told that wood and cement each has a colloidal element. Now wood and concrete are subject to continued deformation under long-time loads. Wood and concrete are also affected in strength by a change of temperature. Wood is hydroscopic. I do not know whether concrete is. All these three properties distinguish colloids. **Mr. Hatt.**

RESULTS OBTAINED WITH THE AUTOCLAVE TESTS FOR CEMENT.

By H. J. Force.

The object of this paper is to give the results of tests on various brands of cement, some of which failed to pass and others of which passed the autoclave test.

The autoclave is shown in Fig. 1. The apparatus for making expansion bars and taking measurements is shown in Fig. 2. With these instruments it is possible to measure to 0.001 in., which gives very satisfactory results.

The autoclave test is made as follows: Three neat briquettes are made up, using water which gives a normal consistency on the Vicat needle of from 7 to 10 mm. The briquettes are kept in the damp closet for 24 hours, at the expiration of which time they are removed from the molds and placed in the autoclave. Sufficient water is added to partly or wholly cover the briquettes, and the instrument closed. The burners are of sufficient size to raise the pressure to 295 lb. in not more than one hour, and this pressure is maintained for one hour longer or a total time of two hours. The pressure is then gradually released, the briquettes are taken out and placed in the moist closet for one hour. They are then broken in the standard cement testing machine in the usual manner. The results from the various mills are the average of three briquettes.

A 1 by 6-in. expansion bar is made up with the briquettes and at the end of 24 hours is measured and placed in the autoclave. The bar is removed with the briquettes at the end of the two-hour test. The final measurement is made after the bar has remained in the moist closet for one hour.

Tables I to V show the results of all tests on the cements from mills Nos. 1 to 5, respectively. For purposes of comparison, there are shown in Table VI the averages of the results of all tests from each mill.

It will be noted that each shipment from mill No. 2 shows a large increase in tensile strength in the autoclave test and with

one or two exceptions the expansions are all very low. The chemical composition of the cement from this mill is about normal. The tensile strengths for the sands on the 7 and 28-day and the 3 and 6-month tests, are all excellent.

Mill No. 1 shows, perhaps, the most uniform results of any of the five mills. This is the first mill in the United States to attempt the manufacture of autoclave cement and is the plant



FIG. 1.—Autoclave.

at which many of the early experiments were conducted. From the day that they started to make shipments of autoclave cement up to the present time there has not been one single cause for rejection, and this is indeed a most remarkable showing. Mill No. 1, like No. 2, shows a continual increase in the tensile strength up to six months.

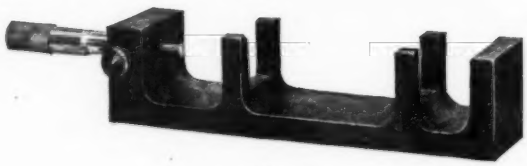
Mills Nos. 4 and 5 also show a wide variation, some of the shipments passing the test, others failing; some showing little

expansion, others showing considerable expansion. The results of the 7 and 28-day and the 3 and 6-month tests are lower in this case than in either mill No. 1 or No 2.

One of the western manufacturers, located in California, has given me his results, which are shown in Table VII. These, I believe, were obtained at the mill laboratory and it is to be noted that the results of this mill compare very favorably with those of mills Nos. 1 and 2, the tensile strengths of the sand briquettes for 28 days being very close to those of mills No. 1 and 2. They are however, a trifle lower, due perhaps to the method of making up the briquettes. The method which



(*a*)



(*b*)

FIG. 2.

is being used in the laboratory of the Delaware, Lackawanna and Western Railroad Co. is one of tamping. About 9 per cent of water is usually used and the briquettes are then well tamped in the molds by placing an iron die thereon and striking it several times with a wooden mallet. This gives higher results on the 7 and 28-day tests, but when the briquettes are very firmly packed in with the thumbs there appears to be very little difference in the long-time tests, except possibly that more uniform results are obtained by tamping.

To all large users of cement, the figures from the various mills are certain to be interesting. The question naturally arises as to why a cement which passes the ordinary boiling test

in many cases, from some of the mills, shows a great decrease in tensile strength or goes entirely to pieces in the autoclave test. In this connection I beg to refer to a paper bearing on

TABLE I.—RESULTS OF TESTS ON CEMENT FROM MILL NO. 1.

Number of Cars Represented.	Tensile Strength, Neat, at 24 hr., lb. per sq. in.	Autoclave Test.				Tensile Strength of 1:3 Briquettes, lb. per sq. in.				Loss on Ignition, per cent.	Chemical Composition.					
		Tensile Strength, lb. per sq. in.	Change in Tensile Strength, per cent.		Expansion, per cent.	7 days.	28 days.	3 months.	6 months.		SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3
			Increase.	Decrease.												
3.....	432	656	51.85	.....	0.15	428	480	484	430	1.40						
4.....	408	636	55.00	.....	0.20	378	375	477	527	1.84						
2.....	423	767	81.32	.....	0.20	379	420	463	467	1.12						
2.....	482	551	25.93	.....	0.15	352	390	463	484	1.20						
2.....	466	575	23.39	.....	0.20	385	398	523	519	....						
2.....	440	737	67.50	.....	0.15	370	405	435	439	....						
6.....	405	680	67.90	.....	0.08	355	415	460	482	....						
3.....	426	672	57.74	.....	0.06	373	405	443	515	....						
2.....	412	644	56.28	.....	0.13	315	388	396	385	....						
4.....	487	755	55.03	.....	0.06	424	468	514	428	....						
1.....	417	671	60.91	.....	0.17	355	452	...	...	....						
3.....	404	660	63.36	.....	0.08	347	404	425	415	....						
2.....	425	608	43.06	.....	0.08	333	406	427	**435**	....						
2.....	420	575	37.00	.....	0.08	370	436	462	**490**	....						
2.....	432	582	34.26	.....	0.13	365	446	420	**417**	1.35						
2.....	455	775	70.33	.....	0.21	349	352	503	**416**	1.18						
2.....	465	585	25.80	.....	0.12	385	531	582	**539**	0.96						
4.....	507	707	39.40	.....	0.10	332	436	479	**403**	1.42	21.12	3.29	7.43	62.55	2.60	1.42
1.....	430	630	46.70	.....	0.13	450	505	...	...	1.16						
3.....	450	666	48.00	.....	0.13	343	431	470	**423**	1.08						
1.....	422	712	70.00	.....	0.08	380	426	...	...	1 44						
2.....	402	510	26.86	.....	0.09	381	492	534	**460**	1.00	21.84	3.30	7.10	61.60	3.73	1.40
2.....	405	775	91.35	.....	0.12	373	418	483	**428**	1.60						
2.....	402	742	84.80	.....	0.31	400	457	453	**428**	0.96						
10.....	455	712	56.50	.....	0.12	412	444	479	**438**	1.32						
6.....	444	789	80.00	.....	0.10	435	514	528	**441**	1.02						
5.....	465	657	41.30	.....	0.11	475	501	478	**490**	0.94						
9.....	468	735	54.90	.....	0.23	447	470	514	**439**	1.34						
12.....	465	690	48.40	.....	0.15	345	441	463	...	1.25						
11.....	440	660	50.00	.....	0.10	460	471	**450**	...	1.17						
10.....	467	728	55.90	.....	0.10	417	536	**513**	...	1.05						
1.....	465	815	75.27	.....	0.10	449	562	...	...	0.96						
10.....	428	754	79.10	.....	0.24	405	494	**455**	...	1.10						
1.....	446	700	57.00	.....	0.10	...	...	...	...	0.77						
20.....	432	714	64.50	.....	0.04	456	438	**412**	...	1.43						
7.....	436	652	49.50	.....	0.15	416	455	**448**	...	1.23						
9.....	410	599	43.30	.....	0.15	370	452	**398**	...	0.98						
3.....	437	600	37.30	.....	0.12	407	490	**521**	...	0.60						
3.....	435	787	80.92	.....	0.25	357	460	**465**	...	0.48						
3.....	340	637	87.35	.....	0.15	415	474	**488**	...	0.45						
4.....	450	682	51.55	.....	0.09	377	417	**452**	...	....						
2.....	456	784	71.91	.....	0.10	435	482	**471**	...	1.02						
4.....	432	825	90.97	.....	0.13	392	448	**451**	...	....						
4.....	438	720	56.86	.....	0.11	447	462	**461**	...	....						
6.....	445	740	66.27	.....	0.10	414	448	**423**	...	1.20						
5.....	442	695	57.24	.....	0.15	383	472	**410**	...	1.30						
5.....	465	762	64.00	.....	0.08	426	452	**466**	...	1.12	20.88		11.52	61.70	2.86	1.58
2.....	456	757	66.51	.....	0.08	440	**468**	**495**	...	0.58	20.86		11.60	62.00	3.03	1.64
2.....	375	590	57.53	.....	0.12	386	**427**	...	...	0.66	20.86		9.70	64.18	2.51	1.74
Average	416	687	57.71	.....	0.13	393	450 **450**	475 **468**	463 **453**	1.10	21.11		10.79	62.40	2.94	1.56

NOTE:—The values in bold-face type did not appear in the paper as originally presented.—ED.

this subject by Henry S. Spackman, published in the *Engineering News*, July 11, 1912; also to another important paper on the Autoclave Boiling Test, by Bernard Enright, Director of the Eastern Testing Laboratories, Allentown, Pennsylvania, published in the *Engineering News*, August 8, 1912. Both of these gentlemen have carefully investigated the autoclave test and their papers bearing on this question are of much value and

TABLE II.—RESULTS OF TESTS ON CEMENT FROM MILL NO. 2.

Number of Cars Represented.	Tensile Strength, Neat, at 24 hr., lb. per sq. in.	Autoclave Test.				Tensile Strength of 1:3 Briquettes, lb. per sq. in.				Loss on Ignition, per cent.	Chemical Composition.					
		Tensile Strength, lb. per sq. in.	Change in Tensile Strength, per cent.		Expansion, per cent.	7 days.	28 days.	3 months.	6 months.		SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3
			Increase.	Decrease.												
6.....	356	674	89.32	.....	0.55	440	543	522	550	2.00						
8.....	335	435	29.85	.....	1.50	355	405	476	454	1.56						
4.....	435	675	55.17	.....	0.15	353	375	458	451	....						
10.....	356	607	73.00	.....	0.10	316	395	455	418	....						
6.....	390	487	25.00	.....	0.40	323	418	426	445	....						
4.....	437	672	53.80	.....	0.10	379	450	472	**487**	....						
3.....	412	515	25.00	.....	0.18	307	375	442	**442**	....						
4.....	362	592	63.54	.....	0.10	350	451	435	**440**	....						
3.....	405	580	43.21	.....	0.17	353	446	511	**442**	1.98						
6.....	480	630	31.25	.....	0.18	333	412	496	**455**	2.34	21.18	2.57	8.23	61.35	2.17	1.49
5.....	389	722	80.00	.....	0.20	433	417	508	**467**	0.92						
5.....	357	641	75.00	.....	0.17	455	505	503	**431**	0.64						
5.....	400	517	29.25	.....	0.30	425	517	516	**473**	1.12						
5.....	425	722	61.00	.....	0.13	432	549	571	**458**	0.78						
4.....	412	660	60.19	.....	0.25	403	508	505	...	0.98						
5.....	425	670	57.64	.....	0.59	381	450	**447**	...	1.23						
5.....	462	691	49.00	.....	0.18	410	471	**454**	...	1.18						
5.....	405	708	53.90	.....	0.17	393	423	**455**	...	1.30						
5.....	440	620	40.90	.....	0.26	367	438	**518**	...	....						
5.....	465	603	28.00	.....	0.22	357	438	**435**	...	0.92						
5.....	428	725	74.58	.....	0.16	418	444	**415**	...	0.55						
10.....	429	630	50.00	.....	0.12	370	408	**482**	...	....						
3.....	323	730	120.00	.....	0.15	385	449	**420**	...	1.40	21.72	10.50		61.08	3.17	1.68
9.....	452	634	40.26	.....	0.12	**345**	**398**	...	...	1.25	20.70	9.38		63.14	3.11	1.69
Average	407	631	54.53	.....	0.27	380 **378**	447 **445**	486 **475**	463 **458**	1.26	21.20	10.23		61.86	2.82	1.62

NOTE:—The values in bold-face type did not appear in the paper as originally presented.—ED.

will be worthy of study to those interested in cement of higher quality.

Samples of cement which have failed in the autoclave test, when retested again after a period of 30 days, 2 months, 6 months and over a year, in most cases pass the autoclave test. In one or two cases, samples which were approximately 15 months old still continued to show no increase in tensile strength; in a few

TABLE III.—RESULTS OF TESTS ON CEMENT FROM MILL NO. 3.

Number of Cars Represented.	Tensile Strength, Neat, at 24 hr., lb. per sq. in.	Autoclave Test.				Tensile Strength of 1:3 Briquettes, lb. per sq. in.				Loss on Ignition, per cent.	Chemical Composition.					
		Tensile Strength, lb. per sq. in.	Change in Tensile Strength, per cent.		Expansion, per cent.	7 days.	28 days.	3 months.	6 months.		SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3
			Increase.	Decrease.												
1.....	318	40	.....	87.39	5.58	332	382	...	...	1.08						
1.....	297	487	64.00	.....	0.75	372	447	...	...	1.04						
2.....	330	597	80.90	.....	0.25	347	390	448	422	....						
1.....	375	472	26.00	.....	0.53	295	387	...	...	....						
3.....	392	387	.....	1.27	0.41	326	350	432	482	....						
1.....	300	305	1.66	.....	1.02	315	397	...	...	....						
1.....	405	528	30.37	.....	0.31	346	408	431	**435**	1.04						
2.....	392	513	30.89	.....	0.10	352	457	450	**410**	1.04						
5.....	335	205	.....	28.80	1.28	357	**397**	**451**	...	1.56	21.40		10.86	60.90	2.88	1.73
Average	349	393	38.96	39.15	1.13	338	402 **402**	440 **442**	452 **437**	1.15	21.40		10.86	60.90	2.88	1.73

NOTE:—The values in bold-face type did not appear in the paper as originally presented.—ED.

TABLE IV.—RESULTS OF TESTS ON CEMENT FROM MILL NO. 4.

Number of Cars Represented.	Tensile Strength, Neat, at 24 hr., lb. per sq. in.	Autoclave Test.				Tensile Strength of 1:3 Briquettes, lb. per sq. in.				Loss on Ignition, per cent.	Chemical Composition.					
		Tensile Strength, lb. per sq. in.	Change in Tensile Strength, per cent.		Expansion, per cent.	7 days.	28 days.	3 months.	6 months.		SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3
			Increase.	Decrease.												
6.....	275	508	84.72	.....	0.20	406	493	535	414	0.88						
5.....	402	232	.....	42.29	2.77	373	461	478	469	1.04						
4.....	332	297	.....	10.54	1.20	401	471	462	482	0.88						
2.....	435	555	27.58	.....	0.50	331	359	475	476	....						
3.....	473	192	.....	59.40	1.87	370	418	483	483	....						
9.....	370	146	.....	60.53	3.68	342	399	470	428	....						
4.....	410	525	28.05	.....	0.31	373	440	408	452	....						
2.....	350	345	.....	1.42	0.25	307	412	406	425	....						
3.....	427	367	.....	14.00	0.70	328	352	424	**493**	....						
1.....	420	27	.....	93.57	Soft	408	402	...	...	....						
1.....	364	270	.....	26.00	1.97	327	435	...	...	....						
1.....	307	475	54.72	.....	....	410	505	...	...	....						
2.....	385	602	56.40	.....	....	348	452	544	**452**	1.16						
9.....	392	9	.....	99.24	Soft	413	443	483	**433**	1.00						
2.....	369	64	.....	80.00	3.10	355	390	454	**440**	1.04						
3.....	378	257	.....	31.50	1.92	413	461	470	**490**	1.08						
1.....	296	459	16.00	.....	0.39	390	473	...	...	**1.36**						
1.....	237	630	87.00	.....	0.20	416	492	...	...	1.06						
2.....	429	495	15.40	.....	0.80	238	433	...	...	1.07						
3.....	396	447	13.01	.....	1.07	390	453	...	...	1.51	20.82		10.28	60.52	3.51	1.72
Average	372	345	42.54	47.13	1.31	367	437	468	453 **457**	1.10	20.82		10.28	60.52	3.51	1.72

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other cases a decrease in tensile strength was shown, while others showed an increase, due to the seasoning process, of over 100 per cent. This points very clearly to the fact that these particular

TABLE V.—RESULTS OF TESTS ON CEMENT FROM MILL NO. 5.

Number of Cars Represented.	Tensile Strength, Neat, at 24 hr., lb. per sq. in.	Autoclave Test.				Tensile Strength of 1:3 Briquettes, lb. per sq. in.				Loss on Ignition, per cent.	Chemical Composition.					
		Tensile Strength, lb. per sq. in.	Change in Tensile Strength, per cent.		Expansion, per cent.	7 days.	28 days.	3 months.	6 months.		SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3
			Increase.	Decrease.												
2.....	347	504	45.24	.....	0.60	385	466	553	491	1.64						
3.....	310	562	81.29	.....	0.60	306	362	457	467	1.68						
6.....	242	388	60.33	.....	0.75	251	315	407	425	....						
6.....	365	392	7.39	.....	1.00	345	355	431	452	....						
5.....	347	83	.....	76.36	4.83	248	287	312	450	....						
18.....	233	260	11.50	.....	0.91	290	358	416	430	....						
3.....	292	472	61.22	.....	0.63	312	320	395	396	....						
4.....	343	267	.....	29.82	2.50	309	380	442	486	....						
4.....	275	135	.....	60.00	0.40	281	370	407	430	....						
6.....	195	410	110.00	.....	0.86	328	385	430	446	....						
7.....	270	62	.....	96.55	2.82	248	355	395	**455**	....						
4.....	268	350	30.70	.....	1.20	273	373	472	**433**	....						
6.....	288	80	.....	76.60	3.12	305	352	417	**438**	....						
5.....	250	337	53.00	.....	0.48	273	346	440	**429**	3.28	21.68	2.61	6.95	61.08	2.92	1.26
7.....	193	235	23.68	.....	1.50	312	402	483	**480**	1.68						
4.....	340	435	28.00	.....	0.48	339	398	438	**439**	1.28						
39.....	272	Soft	Soft	.....	Soft	352	415	550	**488**	1.80						
8.....	285	142	.....	50.00	1.70	309	372	472	**466**	1.88	21.68	2.65	6.83	62.19	**3.16**	**1.34**
1.....	370	565	53.00	.....	0.23	347	477	...	...	2.32	21.80	2.65	6.59	61.39	3.47	1.42
6.....	340	Soft	.....	Soft	Soft	372	433	504	**496**	1.80						
19.....	378	Soft	.....	Soft	Soft	301	371	532	**458**	1.80						
8.....	371	Soft	.....	Soft	Soft	317	382	509	**406**	1.60						
30.....	365	25	.....	90.41	3.44	328	345	453	**433**	1.92						
6.....	360	10	.....	97.00	4.00	308	363	468	**438**	1.84						
16.....	275	Soft	.....	Soft	Soft	388	438	410	**376**	1.92						
6.....	352	Soft	.....	Soft	Soft	307	435	456	**434**	1.60						
6.....	385	432	25.90	.....	0.52	332	441	524	**427**	2.69						
1.....	387	532	37.20	.....	0.43	355	334	...	...	2.63						
4.....	342	500	46.15	.....	0.30	382	424	...	...	2.70						
6.....	372	94	.....	80.00	5.40	430	490	430	...	2.28						
4.....	299	70	.....	76.60	5.00	413	445	484	...	2.18						
1.....	358	143	.....	44.57	3.23	332	390	...	...	2.10						
2.....	261	462	80.00	.....	0.52	258	380	...	...	2.50						
5.....	261	374	33.00	.....	0.70	233	412	**436**	...	1.93						
6.....	216	75	.....	65.30	No Bar	217	457	**485**	...	1.75						
1.....	309	494	59.80	.....	0.06	...	...	...	...	2.39						
3.....	282	410	45.30	.....	0.81	311	395	**413**	...	1.94						
2.....	387	403	11.10	.....	0.68	327	390	**402**	...	2.77						
2.....	216	440	137.00	.....	0.48	361	410	**460**	...	2.06						
3.....	293	430	47.30	.....	0.54	368	466	**471**	...	1.70						
1.....	308	432	40.26	.....	0.36	310	426	**427**	...	2.02						
4.....	407	325	.....	25.23	2.24	370	385	**338**	...	2.66	20.10	10.34		60.42	3.44	1.88
Average	310	314	49.06	66.80	1.52	320	392	453 **448**	447 **437**	2.07	21.31	9.66		61.27	3.25	1.47

NOTE:—The values in bold-face type did not appear in the paper as originally presented.—ED.

samples were not properly manufactured, for with certain mills any cement which has not passed the autoclave on the first test, has in practically every case passed the test after the

cement is held for a period of time. Fig. 3 shows results on samples which have passed and samples which have failed on the autoclave test. All of these specimens passed the regular boiling test.

Further investigation as to why some of these cements fail to pass this test after a period of time shows that the raw material was more coarsely ground than in other samples which did pass the test after seasoning. The grinding of the raw material and the proper burning plays a most important part in the quality of Portland cement; and the author believes that the failure of cement to pass the autoclave test is due very largely

TABLE VI.—AVERAGE OF RESULTS OF TESTS FROM MILLS NOS. 1 TO 5.

Mill No.	Tensile Strength, Neat, at 24 hr., lb. per sq. in.	Autoclave Test.				Tensile Strength of 1:3 Briquettes, lb. per sq. in.				Loss on Ignition, per cent.	Chemical Composition.					
		Tensile Strength, lb. per sq. in.	Change in Tensile Strength, per cent.		Expansion, per cent.	7 days.	28 days.	3 months.	6 months.		SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3
			Increase.	Decrease.												
1.....	416	687	57.71	.....	0.13	393	450 **450**	475 **468**	463 **453**	1.10	21.11	10.79		62.40	2.94	1.56
2.....	407	631	54.53	.....	0.27	380 **378**	447 **445**	486 **475**	463 **458**	1.26	21.20	10.23		61.86	2.82	1.62
3.....	349	393	38.96	39.15	1.13	338	402 **402**	440 **442**	452 **437**	1.15	21.40	10.86		60.90	2.88	1.73
4.....	372	345	42.54	47.13	1.31	367	437	468	453 **457**	1.10	20.82	10.28		60.52	3.51	1.72
5.....	310	314	49.06	66.80	1.52	320	392	453 **448**	447 **437**	2.07	21.31	9.66		61.27	3.25	1.47

NOTE:—The values in bold-face type did not appear in the paper as originally presented.—ED.

to the coarser granules which do not become hydrated when the cement is set up and that the failure of these granules to become fully hydrated is due to their chemical composition. That is, the granules are composed largely of dicalcium silicate ($2CaO:SiO_2$), with a smaller proportion of tricalcium silicate ($3CaO:SiO_2$). Granules of this composition fail to properly hydrate in the period of 24 hours and consequently, when brought in contact with heat and pressure, together with moisture, slaking of the dicalcium silicate is quickly brought about with the result that a large percentage of expansion occurs, together with a proportionate decrease in tensile strength. On the other hand, if the proportion of tricalcium silicate is largely in excess

of the dicalcium silicate, then we may expect a more stable product and one which will show considerably less expansion under the autoclave test and which should remain constant in volume in after years.

In order to produce a large excess of tricalcium silicate two things are necessary; the raw material must be more finely ground and the cement must be burned at a higher temperature. It will be noted that most of the cement in mill No. 2, as well as

TABLE VII.—RESULTS OF TESTS OF CEMENT FROM A WESTERN MILL.

Fineness: per cent passing Sieves.			Tensile Strength, Neat.			Tensile Strength, 1 : 3 Ottawa Sand, lb. per sq. in.	
No. 80.	No. 100.	No. 200.	24 hours, lb. per sq. in	Autoclave Test, lb. per sq. in.	Increase, per cent.	7 days.	28 days.
98.6	95.1	83.8	363.6	576.7	58.6	289.2	381.4
98.6	95.1	83.8	197.5	505.0	155.7	.....	.....
98.4	94.6	84.8	397.5	515.0	29.6	316.2	379.0
98.6	95.0	84.0	418.0	781.0	86.8	.....	.....
98.6	94.7	83.7	333.5	554.5	66.2	341.2	424.8
98.6	94.7	83.7	340.0	717.5	111.0	.....	.....
98.6	94.7	83.7	241.0	497.5	128.3	.....	.....
98.6	94.7	83.7	353.5	556.5	57.4	.....	.....
98.6	94.7	83.7	343.0	658.5	92.0	.....	.....
98.6	94.7	83.7	278.0	620.5	123.2	.....	.....
98.5	94.8	84.0	364.5	632.5	73.3	348.8	403.0
98.5	94.8	84.0	350.0	624.0	78.3	.....	.....
98.5	94.8	84.0	242.0	610.0	152.1	.....	.....
98.5	94.7	83.9	332.5	587.5	76.7	333.6	393.2
98.5	94.7	83.9	377.0	716.0	89.9	.....	.....
98.5	94.7	83.9	274.0	657.5	139.8	.....	.....
98.5	94.6	83.2	350.0	467.5	33.6	338.4	410.2
98.5	94.6	83.2	361.5	666.0	84.2	.....	.....
98.5	94.6	83.2	310.0	605.0	95.2	.....	.....
98.5	94.8	83.2	379.0	463.5	22.3	304.8	409.0
98.5	94.8	83.2	406.0	715.5	76.2	.....	.....
98.5	94.8	83.2	367.0	571.0	55.6	.....	.....
98.6	94.8	84.1	331.5	423.5	27.7	353.0	413.4
98.6	94.8	84.1	388.5	667.5	71.8	.....	.....
98.6	94.8	84.1	351.5	625.0	78.1	.....	.....
98.5	94.8	83.8	376.5	512.0	36.0	327.0	406.8

in mill No. 1, shows very little expansion and a comparatively low loss on ignition. It is also known that in both mills Nos. 1 and 2, the raw material was very finely ground. In some of the other mills, for example, Nos. 3 and 4, while the burning was good, the raw materials were not so finely ground; in mill No. 5, there was not only fairly coarse grinding of the raw material, but there was also a much higher loss on ignition. From the report of mill No. 5, it is evident that the cement from

this mill could not be as constant in volume as that from mills Nos. 1 and 2.

In order to manufacture a cement which will pass the autoclave test it is necessary to grind the raw material very much finer than is customary and to have the clinker well burned. The manufacturer, however, can greatly increase the output of his mill by grinding his raw material coarser and burning his clinker not quite so hard. This produces a cement which contains a very large percentage of dicalcium silicate, which may

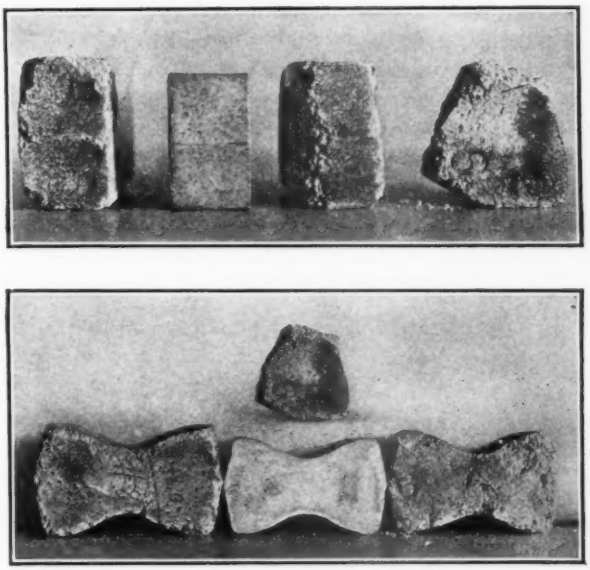


FIG. 3.—Samples from the Autoclave Test.

not be constant in volume, and which would more than likely fail to pass the autoclave boiling test. This cement would probably require seasoning in order to make it pass the regular boiling test.

Briquettes for tensile strength from the various mills have been made up on most of the samples shown, to one year. It is to be expected that the results on cement for long-time tests will be equally as high, if not higher, than on the standard specification cements. On the long-time tests for expansion,

very little difference or variation has been noted to date. A number of expansion bars have been kept under observation and measured at frequent intervals. It is believed that some time must elapse before any difference will be noted in these bars.

A large number of cylinders and cubes have been made up for compression tests. The results to date indicate that higher compressive strengths are being obtained, as a rule, on autoclave cement. A large number of 2-in. cubes of the various brands have been made up for compression tests, to be made during a period of from one to five years. The number tested to date is not sufficient to draw any definite conclusions, except as stated above, that in many cases the autoclave cements show higher strength in compression. The results obtained on autoclave cements are more uniform than on cements which do not meet the autoclave requirements.

I trust that I shall be able to render the Society a report next year on these cements, both as to tensile and compressive strength.

DISCUSSION.

MR. R. J. WIG.—Detailed analysis of the data presented in this paper shows that the results obtained with the so-called autoclave test are dependent upon certain properties of the cement; but it does not show that the test develops any properties which are called into play in service, nor that it identifies a material which service has found to give satisfaction. Mr. Wig.

The results given in Mr. Force's paper are of much interest in connection with the advocation of a high-pressure steam or so-called "autoclave" test as a requirement of the standard specification for cement.

While the Bureau of Standards, and previously the Geological Survey, had considered the value of high-pressure steam as a means of curing or hardening concrete products and realized that there was a difference in the behavior of various cements subjected to steam, no study of this behavior was undertaken until about eighteen months ago.

Referring to available data on the steam or boiling test we find, in the report on Problem 32 on the accelerated tests of the constancy of volume of cements, presented at the Brussels Congress of the International Association for Testing Materials, 1906, the following statement:

"A meeting of the committee held at Brussels, January 26, 1903, attended by representatives from England, Belgium, Denmark, France, and Holland, decided that some form of hot test should be adopted as a standard accelerated test for the constancy of volume of cement."

After conducting a series of tests this committee decided that:

"The ordinary cold-water pat test at 28 days is not capable of detecting with certainty a cement known to be unsound and that it fails completely to detect a cement of doubtful soundness."

Quoting from the report of the committee at the Copenhagen Congress in 1909, we find the following:

"It is also clear that tests at 15° C. and 50° C. do not suffice to detect a doubtful or unsound cement with certainty, but that when the test is

Mr. Wig. carried out at 100° C. as originally prescribed by Le Chatelier, it is easy to detect even a doubtful cement, whereas a sound cement withstands the test perfectly, expanding to the extent of only a few millimeters."

Again, a little further along in the committee report the following statement is made:

"Without exception the cold pat test at 28 days was inadequate to detect with certainty doubtful samples or even samples thoroughly sound. The tests at 50° C. sufficed to detect doubtful samples. The only perfectly reliable tests were those at 100° C."

And as a concluding remark the committee reports that:

"The question of the constancy of volume of cements has now been advanced to a point where a definite conclusion can be stated. The experiments carried out under the auspices of Committee 32 showed that an accelerated test at a high temperature could be fulfilled without difficulty by modern cements carefully manufactured and of high quality. It also showed that cements of doubtful quality were not easily distinguished from those which were free from all defect except by a high temperature test. All cold-water tests and hot tests which were simply qualitative were found to be inadequate. Nothing which has occurred since the date of the committee's report has tended to invalidate this conclusion, but a good deal has happened to confirm it."

Referring to the report of M. E. Deval at the Copenhagen Congress, 1909, in which he carried on a number of experiments to determine the effect of hot water, we find the following:

"To sum up, we may say, that although it does not appear possible from the strength point of view to found upon the hot-water test a method for the rapid testing of cements, the hot-water treatment nevertheless yields valuable information in enabling the presence of expansive ingredients to be detected."

The conclusion of Prof. F. Schule, of Zurich, as delivered at the New York Congress in 1912, was that:

"The accelerated boiling test at 100° C. supplies us with a reliable means of eliminating doubtful cements."

As is observed, these opinions are unanimous in the conclusion that the hot test at 100° C. is of value in detecting a poorly balanced cement and should be included in a specification.

Mr. Wig. The German Association is opposed to any form of boiling test as stated in the paper presented by Professor Gary at the New York Congress of 1912. A rather comprehensive series of tests conducted in collaboration with the Royal-Mechanico-Technical Laboratory at Charlottenburg showed that cements which failed under the hot tests were found perfectly satisfactory when used in the manufacture of concrete products and exposed to the weather for ten or twelve years. They showed no extraordinary change in volume as would be evidenced by cracking or warping.

None of these many opinions are supported by positive data showing that the hot test truly brings about an acceleration of the normal hardening process, nor that such is not the case.

The claim is made that there is no analogy between the exposure of a cement in the autoclave and ordinary exposure in construction work, and therefore the test should be rejected.

A test may be made for one of two purposes, either to identify a material which experience has determined would give satisfaction in service, or to determine the value of some specific property which is to be called into play in service. The specific gravity, fineness and chemical tests are strictly identification tests and do not furnish any information on the properties of cement which are called into play in service. Also our tensile strength, time of setting and soundness tests only indirectly furnish information concerning the useful properties, and may be considered in main simply identification or control tests, made for the purpose of identifying a material which service has shown to be satisfactory.

It is doubtful if there are any who question but that the present steam test conduces to a more uniform product by requiring closer mill control, and there are few even among the manufacturers who would advocate the elimination of this test.

It is a question as to whether there is any analogy between the present steam test and the proposed autoclave test, and if there be such analogy, as to how far removed it is from the present test. Are the compounds formed at 100° C. entirely different from those formed at 215° C. (20 atmospheres pressure)? If so, where are the critical points, or inversion tem-

Mr. Wig. peratures at which the changes take place? Is the behavior of a cement in the autoclave dependent upon the care used in manufacturing the product, as controlled by the proper proportioning and mixing of the raw materials and the burning or subsequent seasoning, which we all recognize as elements conducive to a uniform and satisfactory structural product? If this is the case the test is a good one as a control or identification test, regardless of the compounds which may be formed in the presence of the steam. If such is not the case, however, and the reactions are not dependent upon factors which we recognize as giving a uniform and satisfactory structural product, the test is useless even as an identification test and should be discarded.

The economic features of the adoption of such a test should not be overlooked, for while it may be that a test will produce what might be called a "pure" product, its value as a structural material as indicated by its cementing value may not warrant the greater expense, and a test of less severity may insure the "good enough" or satisfactory product which should be our ultimate aim.

An analysis of available data indicates that the present atmospheric steam test is a valuable control test, and that up to 100° C. the efficiency of the control is proportional to the temperature of the test.

The following tests have been made by the Bureau of Standards:

1. ROUTINE SOUNDNESS TESTS.

In order to ascertain just what proportion of the cements as at present manufactured were sound in high-pressure steam, all routine samples received in the laboratory were subjected to a high-pressure steam test. The results are shown in Table I. As the amount of cement that could be spared from the routine sample for this test was necessarily small, the standard soundness pat was used as a test piece in place of the briquettes. A sample was said to pass the test when the pat remained sound after being subjected to a steam pressure of 300 lb. for 1 hour, the total time in the autoclave being 3 hours.

TABLE I.—RESULTS OF TESTS IN HIGH-PRESSURE STEAM. Mr. Wig.

PORTLAND CEMENT.

No. of Samples Tested.	Samples Sound.	Samples Unsound.	Brands Sound.	Brands Unsound.	Brands sound at one time and unsound at other times.
1093	773	320	42	23	17[a]
WHITE PORTLAND AND NATURAL SO-CALLED "NON-STAINING" CEMENTS.					
190	172	18	6	2	2[a]

[a] These brands are included in other two columns.

2. LINEAR EXPANSION OF PORTLAND CEMENT.

The purpose of this test was to ascertain the comparative linear expansion of cements which were sound and unsound in high-pressure steam.

The test pieces, which were 1 by 1 by 13-in. neat cement prisms, were stored in air, stored in water, and treated in high-pressure steam, and the linear change of test pieces under each condition was studied. The amount of expansion was found by means of a mounted micrometer screw which read to ten-thousandths of an inch, and the expansion is expressed in percentage of the original length, 13 in.

In these tests, a cement was said to have passed the high-pressure steam test when in the form of a standard soundness

TABLE II.—RESULTS OF TESTS OF LINEAR EXPANSION OF PORTLAND CEMENTS.

No. of Samples Considered.	Type of Cement.	Average Percentage of Increase in Terms of Original Length (13 in.).					
		Stored in Air.		Stored in Water.		Treated in Steam.	
		Age in Months.		Age in Months.		Pressure, lb.	
		1 to 2.	6 or over.	1 to 2.	6 or over.	100.	180–300.
22	2	....	—0.305	....	....	....	....
6	2	—0.17	....	....	....	....	....
5	2	....	....	....	+0.16	....	....
3	2	....	....	+0.08	....	....	....
4	2	....	—0.27	....	+0.15	....	+3.5
8	2	....	....	....	....	....	+4.2
2	3	....	—0.32	....	+0.165	....	+0.14
6	3	....	—0.265	....	....	....	....
3	3	—0.19	....	....	....	....	....
2	3	....	....	....	+0.155	....	....
10	3	....	....	....	....	....	+0.135
1	3	....	....	....	....	+0.06	....

Mr. Wig. pat it remained sound when subjected to 300 lb. steam pressure for 1 hour, total time in the autoclave 3 hours. Cements passing the 212° F. steam test but failing in the high-pressure steam test were called type 2 cements, while cements passing both tests successfully are reported as type 3 cements. The results are reported in Table II.

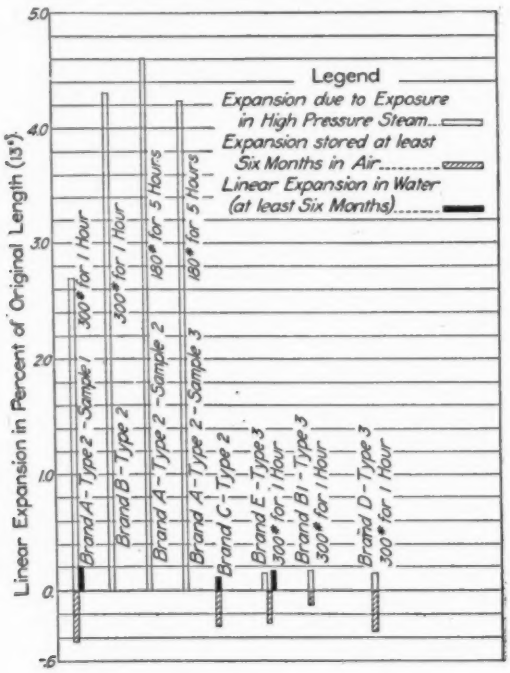


FIG. 1.—Diagram showing Relative Linear Expansion of Cements "Sound" and "Unsound" in the Autoclave Test.

The comparison of the expansion or contraction of cement in air, water and high-pressure steam is shown diagrammatically in Figs. 1 and 2.[1]

Effect of Variation in Steam Pressure on Linear Expansion.—Linear expansion test pieces of seven cements were made, stored in damp room for 24 hours, were then subjected to 100 lb.

[1] Acknowledgment is made to the *Engineering Record* for the use of the cuts of Figs. 1 and 2 of this discussion.—ED.

steam pressure for at least 5 hours, and the linear expansion determined. These same test pieces were then subjected to 180 lb. for at least 5 hours, and in some cases to 275 lb. for 5 hours, and the linear expansion determined. The results of these experiments show that the linear expansion at 100 lb. steam pressure is less than that at the higher pressures (180 to 275 lb.) by an average of 0.02 per cent. Mr. Wig.

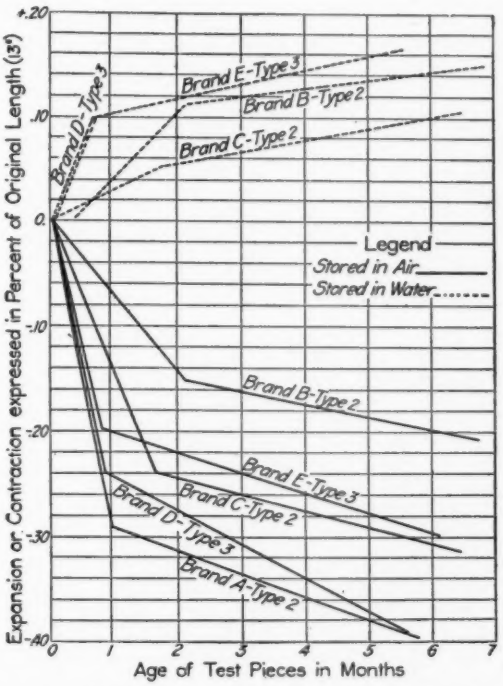


FIG. 2.—Linear Expansion in Air and Water of Cements "Sound" and "Unsound" in the Autoclave Test.

Expansion or Contraction Subsequent to Treatment in High-Pressure Steam.—Several of the expansion test pieces were placed in air and some in water after they had been treated in high-pressure steam (180 lb. for 5 hours) and the linear change was found at various intervals. Results of these tests show that after storing a month in air, subsequent to treatment in high-pressure

Mr. Wig. steam, the average change is less than 0.01 per cent, while 6 months after the steam treatment the test piece has changed an average of less than 0.05 per cent. In water less than one month after steam treatment, the average change in length is less than 0.03 per cent.

3. LINEAR EXPANSION OF PORTLAND-CEMENT MORTARS.

To one cement failing in the high-pressure steam test (type 2 cement), an equal part of standard Ottawa sand was added and the linear expansion after subjection to high-pressure steam (180 lb. for 5 hours) was determined. A similar test piece of a 1:2 mixture of cement and sand was made, treated and tested as above. It was found that the linear expansion of the 1:1 mortar was 96 per cent of that of the neat cement, and the 1:2 mortar was 69 per cent of that of the neat. All test pieces received the same steam treatment.

4. EFFECT OF FINENESS ON SOUNDNESS OF CEMENTS.

A cement passing the standard fineness and soundness tests but showing unsoundness in the form of a pat in the autoclave at 300 lb. for 1 hour, total time in the autoclave 3 hours, was separated into that passing the 200-mesh sieve and that retained on the 200-mesh sieve.

Each kind was made into a neat cement pat and subjected to 300 lb. steam pressure for 1 hour, total time in the autoclave 3 hours. The pat made of cement retained on the 200-mesh sieve completely disintegrated, but the pat made of cement passing the 200-mesh sieve showed no signs of disintegrating, cracking or warping.

A mixture of 1 part cement passing the 200-mesh sieve with 1 part retained on the 200-mesh sieve, when made into a pat and treated in steam at 300 lb. for 1 hour, total time in the autoclave 3 hours, completely disintegrated. A mixture of 1 part cement retained on the 200-mesh sieve with 2 parts cement passing the 200-mesh sieve also disintegrated, but in this case the disintegration was not so marked or complete.

Many of the samples reported as sound in high-pressure steam under "Routine Soundness Tests" were relatively coarse

cements; that is, only 76 to 80 per cent passing the 200-mesh sieve. Mr. Wig.

One cement having 79 per cent passing the 100-mesh sieve, and 61 per cent passing the 200-mesh sieve, was sound in high-pressure steam.

The coarse material retained on a 200-mesh sieve was removed from a cement which was sound and showed the 25-per-cent increase in tensile strength after exposure to high-pressure steam. It was tested and found to entirely disintegrate in the form of a pat in high-pressure steam.

5. EFFECT OF AGE ON SOUNDNESS OF CEMENTS THAT ORIGINALLY FAILED IN HIGH-PRESSURE STEAM.

About 30 samples of cements, all sound in the standard steam test but unsound when subjected in the form of a pat to 300 lb. steam pressure for 1 hour, total time in the autoclave 3 hours, were stored in air-tight glass jars and retested in high-pressure steam at various intervals. The results of these tests indicate that a cement originally unsound in high-pressure steam will become sound if permitted to age from 2 to 6 months.

On most of the above cements a number of pats were made up at a time when the cement was unsound in high-pressure steam. These pats were stored and tested at subsequent intervals in high-pressure steam. In all cases these pats when subjected to high-pressure steam disintegrated as in the original test. This indicates that after hydration, age has little effect on the soundness of cement in high-pressure steam.

6. EFFECT OF VARIOUS STEAM PRESSURES ON THE HARDENING OF CEMENT MORTARS.

A study of the effect of the various steam pressures on cements passing the standard steam test is shown in Table III. This table includes results of tests of steam-treated specimens when 2 days old (just after removal from the autoclave) and similar results of tests when the steam-treated specimens are 28 days old. The results show that after the steam pressure has been raised to 100 lb. there is practically no increase in either compressive or tensile strength from 48-hour to 28-day tests.

Mr. Wig. The maximum tensile strength appears to have been attained with 140 lb. steam pressure. The maximum compressive strength had not been reached at 180 lb. steam pressure.

TABLE III.—EFFECT OF VARIOUS STEAM PRESSURES ON TENSILE AND COMPRESSIVE STRENGTH OF 1:3 PORTLAND-CEMENT STANDARD OTTAWA-SAND MORTAR.

Cement.	Steam Pressure, lb. per sq. in.	Tensile Strength, lb. per sq. in.		Compressive Strength, lb. per sq. in.		Remarks.
		Age.		Age.		
		48 hr.	28 days.	48 hr.	28 days.	
A	10	118	261	....	....	All subjected to steam at stated pressures for 5 hr. unless otherwise noted. Both cements "A" and "B" passed the standard soundness test. All test pieces placed in boiler after 24 hr. in damp room. All values are the average of three test pieces.
A	20	117	218	1 915	2 591	
A	40	115	190	1 176	2 262	
A	60	151	215	1 750	2 385	
A	80	195	260	1 890	2 178	
A	100	294	315	2 397	2 867	
A	100	381	366	....	....	
A	100	514[c]	425[c]	....	....	
A	120	385	358	2 485	2 353	
A	140	410	411	2 965	2 537	
A	160	363	355	2 912	2 327	
A	180	362	288	3 198	3 050	
A	180	369[a]	256[a]	3 416	3 079	
A	180	398[b]	272[b]	....	....	
B	200	245	288	....	....	
B	275	218[d]	193	....	....	
B	225	211[e]	219	....	....	

[a] Two periods of 5 hr. each.
[b] Three periods of 5 hr. each.
[c] Age 7 days. Under pressure of 100 lb. for 15 hr.
[d] Exposed to 1 period of 5 hr. at 200 lb. pressure, then 1 period of 5 hr. at 275 lb. pressure.
[e] Exposed to 5-hr. periods each, at 200, 275 and 225 lb. pressure.

7. COMPRESSIVE STRENGTH OF PORTLAND-CEMENT CONCRETE.

Seventeen sets, totaling 765 concrete cylinders 8 in. in diameter by 16 in. in length, of 1 part Portland cement, 2 parts river sand, and 4 parts river gravel mixed to a mushy consistency, were made to be tested at various intervals up to

ten years. In seven of the sets the cements used passed the standard 212° F. steam test, and when subjected in the form of neat briquettes to 300 lb. steam pressure for 1 hour, total time in the autoclave 3 hours, showed an increase in tensile strength of at least 25 per cent over the untreated cement of the same age. These sets of cylinders are said to contain type 3 cement. Six sets contained cements that passed the standard 212° F. steam test, but failed to give 25 per cent increase in tensile strength, and were unsound in the form of a pat when subjected to 300 lb. steam pressure for 1 hour, total time in the autoclave 3 hours. These are designated as type 2 cements. Four sets of cylinders

Mr. Wig.

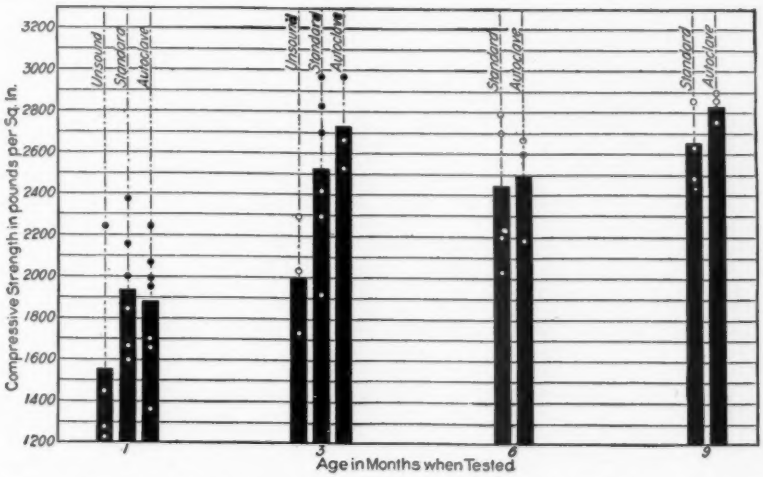


FIG. 3.—Compressive Strength of Concretes made with Various Cements. 1 part Portland Cement, 2 parts River Sand, 4 parts River Gravel. Stored in Air and Exposed to Atmospheric Conditions.

contained cements which failed to pass the standard 212° F. steam test. The cements in these cylinders are referred to as type 1 cements. Seventeen different samples of seven different brands of cement are included in this series of tests and in some cases there are three types of one brand.

Fig. 3 shows the results up to the 9-month period in so far as the tests have been completed.[1] All test pieces were stored in air, subject to atmospheric conditions.

[1] Acknowledgment is made to the *Engineering Record* for the use of the tracing from which the cut of Fig. 3 was made.—ED.

SUMMARY.

Mr. Wig. This summary should be considered as tentative, few of the tests extending over more than nine months, and many of them being only of a preliminary nature.

1. Eighty-eight per cent of the brands of a total number of 48 brands tested passed the autoclave soundness requirement upon some tests, 52 per cent of the brands passed upon all tests, and 6 brands failed to pass the autoclave upon all tests.

2. There is no difference in the linear expansion between type 2 and type 3 set cements which are exposed in the atmosphere for a period of six months.

3. There is no difference in the linear expansion between type 2 and type 3 set cements which are immersed in fresh water for a period of six months.

4. The linear expansion of different cements varies from 0.135 to 4.2 per cent of the original length when exposed to steam at pressures between 180 and 300 lb. per sq. in. The type 3 cements had an expansion below 0.2 per cent and the type 2 cements had an expansion above 2.0 per cent.

5. The linear expansion of set cements exposed to steam increases slightly as the steam pressure increases. (Samples tested show an average increase of 0.02 per cent for pressures ranging from 100 to 275 lb. per sq. in.).

6. Set cements show very little change in volume upon storage in air or water after being subjected to high-pressure steam.

7. Samples of apparently sound cements and concretes have been taken from structures one year or more old, and found to disintegrate upon being subjected to high-pressure steam. Samples of concrete of poor quality have been taken from structures one year or more old, and found to show no physical change upon being subjected to high-pressure steam, while other samples of concrete of apparently poor quality entirely disintegrated.

8. The expansion of a 1:1 or 1:2 cement-sand mortar made with type 2 cement exposed to high-pressure steam shows more than 50 per cent of the expansion of the same cement neat exposed to high-pressure steam.

9. Of cements which are normally unsound in the ordinary atmospheric steam or autoclave steam test, if the finer size

particles are removed, they will be found more sound if tested in the same manner as the original cement, and in many cases entirely sound. While fineness is not essential to soundness, it is the coarser particles of a normally unsound cement which cause the expansive action. Mr. Wig.

10. A cement originally unsound in the autoclave test will usually become sound in from two to six months.

11. If the cement is hydrated and formed into a test piece while it is unsound, it will not become sound upon aging for several months, even though the test piece is stored in water.

12. The maximum tensile strength of sound cement exposed to steam appears to be attained at a pressure not exceeding 150 lb. per sq. in.

13. The compressive strength tests of concretes made from the three types of cement, No. 1 cement failing to pass the standard atmospheric steam test, No. 2 cement passing the standard steam test but not passing the autoclave test, and No. 3 cement passing both the standard steam test and the autoclave test, show a tendency for type 1 cements to develop the least strength and type 3 cements the greatest strength, although the range of values is not very great. These results however should be considered somewhat tentative.

CONCLUSION.

Sufficient data have not been advanced to justify a conclusion as to the merits of the proposed autoclave test of cement, nor to warrant its adoption into a specification; but further investigation should be made and due consideration given to a hot test of greater severity than the present standard steam test.

[1] MR. H. S. SPACKMAN.—Mr. Force's paper is of great importance to all manufacturers and users of Portland cement, not because of the discussion it has aroused, as to the value of the autoclave test *per se*, but because it raises the question of the value, for predicting behavior in the work, of the tests prescribed by our Standard Specifications for Cement for con- Mr. Spackman.

[1] This discussion was prepared for presentation at the annual meeting, and therefore without reference to the values distinguished by bold-face type added to Tables I to VI, inclusive, by the author of the paper subsequent to its presentation.—ED.

Mr. Spackman.

stancy of volume. Mr. Force has referred in his paper to a paper published by me in *Engineering News*, July 11, 1912, as explanatory of the reason why certain cements which pass the ordinary boiling test should subsequently show loss of strength over long-time periods. In connection with this discussion, I wish to make clear that the object of that paper was to show that there were certain expansive forces latent in cement (distinct from the blowing characteristic of over-limed or improperly manufactured cement) which the ordinary boiling test fails to disclose. It is generally recognized that change in volume of concrete construction is due to three causes, two of which are temporary; that is, change in volume due to temperature changes, expansion and contraction due to variation in the moisture present in the concrete; the third change in volume is permanent and is due to the expansion consequent on the retarded hydration of the lime compounds in the cement. The extent of movement in the first two causes can be predicted and taken care of in the design of the structure and causes no loss in strength if the structure is free to accommodate itself to them. The third is, as yet, an unknown quantity and its value is entirely a matter of speculation and is possibly variable with each cement. It is not detected, as far as my investigations go, by the ordinary test for soundness; and I am disappointed in Mr. Force's paper, as I had hoped that Mr. Force's further investigations would show a definite relation between the ability of the cement to pass the autoclave test and its subsequent stability or lack of permanent change of volume when used in the work. In this disappointment I feel all manufacturers of Portland cement will share, for I am confident that they are equally as desirous as are engineers of the formulation or development of a test, which will be positive for determining the freedom from disintegration of concretes or mortars made from their product, caused by the expansion of a portion of the cement after initial hardening.

I have long been of the opinion that certain internal strains may be developed in structures depending for their binding effect upon Portland cement, by the expansion of the intermediate-size particles of cement. In such cases, the durability of these structures is dependent on the cohesive force

developed exceeding the expansive force due to the retarded hydration of the intermediate-size particles. It is to this that I attribute the drop often observed when cement is tested over long periods under tension. While I fully recognize that under actual working conditions, concrete would rarely, if ever, be subjected to conditions such as those found in the autoclave test, this, to my mind, does not constitute a reason for condemning the test, provided it can be shown that there is a relation between the effect produced by these abnormal conditions and the effect of time under normal conditions; but so far, the published results of tests made with the autoclave, including those in Mr. Force's paper now under discussion, fail to show this relation, or that cement passing the proposed test will give greater strength over long-time periods. Mr. Spackman.

Considering Table I of Mr. Force's paper, in which all the cement passed the autoclave test, the average at the 6-month period, though incomplete, due to the fact that a number of the tests are not carried to the 6-month period, shows a reduction in the tensile strength of 12 lb. Considering only the tests that extend to the 6-month period, we find that the 1:3 sand briquettes show at 3 months an average of 462 lb., and at 6 months an average of 462 lb., or no gain. An analysis of the individual breaks, however, shows that out of the eleven tests carried to the 6-month period, of all the cements passing the autoclave test, five show a retrogression, while six show a gain.

Considering Table II, we find that while all cement passed the autoclave test, the average including the short-time test of cement not carried to the 6-month period, shows a retrogression of 23 lb. between the 3 and 6-month periods; and of the five tests carried to the 6-month period, three show retrogression, and two show gains.

Referring to Table III, where out of nine tests, three failed to show an increase when tested in the autoclave, the average, though incomplete, shows a continued gain in strength up to the 6-month period, but of the two cements carried to the 6-month period, the one showing the largest increase under the autoclave shows a loss of 26 lb. and the one showing a decrease of 1.27 per cent shows an increase of 50 lb.

The same conditions will be found by an analysis of

Mr. Spackman. Table IV. The average of all tests shows a decrease in strength under tension at the 6-month period.

Considering the eight tests which are carried to the 6-month period, we find that three showed an increase in strength under the autoclave test and five a decrease; that of the three cements showing an increase under the autoclave test, one showed a marked decrease at 6 months over the 3-month period, amounting to 121 lb., or over 20 per cent. The other two show gain. Of the five tests showing a decrease when tested under the autoclave, two show a decrease and three an increase at the 6-month period; the average of the cements passing the autoclave test at 3 months being 473 lb. and the average of the same cements at 6 months being 447 lb. or a decrease of 26 lb. Of the five cements showing a decrease under the autoclave test, the average at 3 months is 460 lb., while at 6 months these cements showed an average of 457 lb. or a decrease of 3 lb. against 26 lb.

In Table V the average, which again includes a number of results obtained at the 7-day, 28-day and 3-month periods which have not been carried to the 6-month period, shows a decrease at the 6-month period over the 3-month period for average of all the tests.

Analyzing the test carried to the 6-month period, we find seven showing an increase under the autoclave test and three a decrease; and that the seven passing the autoclave test show an average increase at 6 months over the 3-month test of 3 lb. Of the three cements failing to show an increase under the autoclave test, we find a marked increase in strength at the 6-month period; the average for the three cements at 3 months being 387 lb. against 455 lb. at 6 months, or an average gain of 68 lb. for the cement that failed to pass the autoclave test; and it is noticeable that the cement which showed the greatest decrease in strength under the autoclave test showed the most marked increase.

If we accept that there is any relation between the behavior of the test piece under standard laboratory conditions and the behavior of mortar or concrete made from the same cement on the work, the results of the test given by Mr. Force seem to

negative his claim, that cement passing the autoclave test will give better results in the work than cements failing to do so. **Mr. Spackman.**

I do not wish this discussion to be understood as condemning the autoclave test, for I believe it may have possibilities and shall await with interest further reports by Mr. Force and other investigators, which I hope will be coupled with observation of the behavior of the cement used on the work; but I frankly admit that until such relation is shown, I would not recommend the inclusion of the autoclave test in any specification.

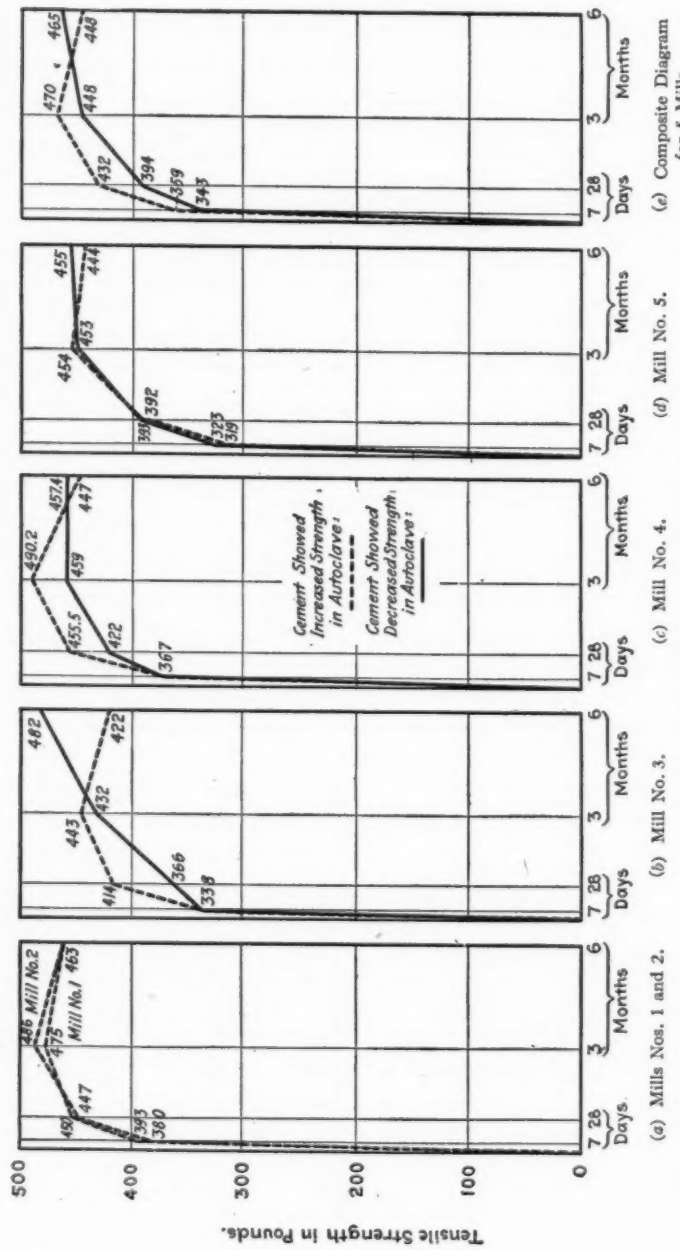
Taking up the explanation given by Mr. Force of the retarded hydration of the coarser granules, I should like to know on what experimental data, if any, this is based. From my observation, any clinker composed largely of dicalcium silicate will disintegrate and fall to a fine powder. The dusting clinker is also easier to grind, and I would anticipate a much greater content of fine flour in a cement made from clinker high in dicalcic silicates than from a clinker in which this compound is largely absent. It is, however, possible that the dicalcic silicate may hydrate with time and be responsible for expansion, not by reason of its coarseness of grain, but because it is sparsely, if at all, attacked by water at normal temperatures.

The thought is a new one to me and I shall be glad to hear the opinion of others as to the possibility that the retarded hydration of a portion of the cement is due to the presence of dicalcic silicate, even though finely divided, as well as to the presence of coarser granules.

[1]MR. LEWIS R. FERGUSON.—In confirmation of the remarks of Mr. Spackman, I desire to draw further attention to the significance of certain of the figures given in the paper by Mr. Force. **Mr. Ferguson.**

First, taking up the question of the amount of expansion which a cement shows in the autoclave: I understand that Mr. Force claims that the cement showing the least expansion in the autoclave would show ultimately the greatest strength. Judging from the tests shown in Mr. Force's paper, this conclusion is unwarranted. Of the samples of cement

[1] This discussion was prepared for presentation at the annual meeting, and therefore without reference to the values distinguished by bold-face type added to Tables I to VI, inclusive, by the author of the paper subsequent to its presentation.—ED.



(a) Mills Nos. 1 and 2. (b) Mill No. 3. (c) Mill No. 4. (d) Mill No. 5. (e) Composite Diagram for 5 Mills.

FIG. 4.—Tests of Cement from Various Mills.

tested from mill No. 1, the ones which show a decrease in tensile strength between the 3 and 6-month periods have less expansion in the autoclave than the cements which show an increase between these periods. Mr. Ferguson.

In the tests from mill No. 2, the sample which gave next to the greatest strength at 6 months had an expansion in the autoclave of 1.5 per cent, and the sample having the least expansion, 0.10 per cent, showed the least strength at the age of 6 months.

In the tests shown from mill No. 3, of the two tests given at the 6-month period the one having the greater expansion had the greater strength.

In the tests from mill No. 4, the cement showing next to the greatest decrease in the autoclave gave the greatest strength at the age of 6 months.

In the tests from mill No. 5, the cement which gave a tensile strength of 450 lb. at 6 months, slightly higher than the average, showed an expansion of 4.83 per cent—the greatest expansion shown for cements covered by the 6-month period.

I understand also that Mr. Force claims that in certain cements there exist coarser granules which do not become hydrated when the cement sets. These coarser granules are supposed to cause a lack of constancy of volume in the mortar or concrete when they do hydrate. The autoclave is supposed to detect the presence of these coarser granules. If such is the case, it would be supposed that cements which show a decrease in strength in the autoclave would show a decrease in strength between certain periods and that a cement which showed increased strength in the autoclave would show a steady increase in strength with age. Taking Mr. Force's figures from the various mills he has tested, we find that this is not the case. As a matter of fact, the averages of the cements which gave an increase in the autoclave invariably show a retrogression in strength between the ages of 3 and 6 months, while the averages of the cements which gave a decreased strength in the autoclave show a steady increase as far as the tests have been carried, with practically no retrogression. These results are shown graphically in Fig. 4.

Mr. Enright. MR. BERNARD ENRIGHT (*by letter*).—It is natural that an engineer who is responsible for an important piece of work would prefer to use a cement that passes the soundness test rather than one that does not. And any additional test which he thinks would still further demonstrate the soundness of the product, and which it is possible for a properly manufactured cement to pass, should naturally also appeal to him; particularly if the work is one involving heavy responsibility, as in bridges, dams, etc. The autoclave test was evidently advanced with this view in mind.

It is readily possible to manufacture autoclave cement if the manufacturer is willing to take the pains and incur the somewhat additional expense to do it. While aging of the clinker and aging of the cement helps to achieve soundness in the autoclave, there are plants producing autoclave cement from fresh clinker and without seasoning the product in the stock house. At one plant with which I happen to be familiar, the inspector for the consumer, who has placed a large contract for autoclave cement, took samples two or three times a week, prior to the award of the contract, visiting the plant at all times without notification, and taking the samples, not from bins in the stock house, but from the stream of fresh cement direct from the mills, in order to insure that autoclave cement could be made with reasonable regularity.

The purchaser's line of tension tests on these samples, on 1 : 3 sand mixtures, ranged from 350 to 400 lb. per sq. in. in seven days, and around 500 lb. per sq. in. in 28 days. This is not exceeded by any cement made any place.

Compression tests on this autoclave cement 1 : 3 sand mixtures, made in the German standard compression apparatus and according to German specifications, have shown as high as 400 kg. per sq. cm. (equivalent to about 5700 lb. per sq. in.) in seven days, and close to 600 kg. per sq. cm. (8500 lb. per sq. in.) in 28 days. These are the highest of any cement of which I have seen records, emphasizing the superior quality of this autoclave cement. German specifications require only 120 kg. per sq. cm. (about 1700 lb. per sq. in.) in 7 days, and 250 kg. per sq. cm. (about 3550 lb. per sq. in.) in 28 days, on the same 1 : 3 sand mixtures.

Mr. Enright.

A California plant, which I have recently visited, was making autoclave cement the greater part of the time, and about ninety per cent of the product from at least one Lehigh Valley mill is regularly passing the autoclave test. Other plants in this district are shipping on autoclave specifications without any difficulty. All of which goes to show that the specification is by no means unreasonable or impossible of attainment.

Mr. Carpenter.

MR. R. C. CARPENTER.—I have been much interested in the paper by Mr. Force on the results obtained with the autoclave. This paper brings before the engineer another method for testing of "constancy of volume" which is much more severe than any method in common use.

From the paper, one can group all these different cements into classes, one class passing the autoclave test and the other not passing it. While the paper presents the results of numerous tests made on both classes of cement, it does not, it seems to me, fully establish the value of the autoclave for accelerated tests, nor does it prove that the cement accepted by the autoclave is superior to that which is accepted by the standard tests now in use and rejected by the autoclave.

I believe it will be found, on investigation of the various proposed methods of determining the constancy of volume, that the test is not new fundamentally; its novelty lies in the type of apparatus employed. The test is especially severe, because of the high temperature to which the cement sample is subjected, and also because of the form of the specimen. The form is one likely to be affected by expansion strains; whereas the thin pat employed in the standard tests is largely free from expansion due to sudden heating and cooling.

It is interesting to note that the character of the Portland cements on the market, as well as the system of manufacture, has radically changed during the last twenty-five years. This has been largely due to methods of testing and to specifications. The recent cements attain high tensile strength in a very short period of time, as compared with the older cements, and recent investigations have indicated, in many cases, a tendency for many of the cements to retrograde somewhat in strength instead of increase in strength with age. The present specifications for Portland cements require, roughly speaking, about

Mr. Carpenter. double the tensile strength for the one-day test and for the week test as those of twenty-five years ago. The characteristic curves, representing the increase of tensile strength with age, have changed greatly during the period mentioned. The cement of twenty-five years ago had a characteristic strength curve which increased at a much less rate during the early periods than is the case with the curve of the recent cements; yet at the end of one year, the difference in tensile strength of the cement of the period of twenty-five years ago, as compared with that of the recent cement, is very small. The old cement was free from retrogression. It was put on the market comparatively coarsely ground and, in chemical composition, it contained considerably less lime than recent cement. Our accelerated methods have led to the production of an improved cement as compared with the process of twenty-five years ago, so far as quick hardening or attaining quick strength is concerned. The requirements for early hardening may go too far, especially when the question of permanence is given consideration.

I have called attention to the difference in characteristics between the earlier cements and those on the market at the present time, in order that consideration may be given the question whether we are making an over-estimate of the value of steaming tests. I think serious consideration should be given as to the desirable requirements for the strength of cements at different ages. It is important in my opinion that the cement should have permanent value and, if possible, should attain its maximum strength after the lapse of considerable time rather than during two or three months. At least, it is certainly desirable that there be no material retrogression.

The English, French, and American engineers have adopted as the standard requirement in most specifications, a simple steaming test for cements. The manufacturers in these countries have had no difficulty in producing cement that will meet such standard specifications and are very well satisfied, for that reason, with the present requirements. I personally believe that the standard steaming test is of great value, but I would not rely on it solely for accepting or rejecting a cement. The German manufacturers, while employing a similar test in their

own works, discourage the use of such a test for the purpose of determining the value of the cement sold. The steaming test has been rejected as part of the German standard specifications, for the reason that in many cases it rejects cement known to have superior qualities, and in other cases accepts cements of inferior value. The long-time cold-water test is regarded by the Germans as the only conclusive test of constancy of volume. Mr. Carpenter.

The autoclave cements will, I am quite certain, be more expensive to manufacture than those which do not pass the autoclave test. This is indicated by certain statements in the paper by Mr. Force, and is also in accord with my knowledge of the manufacture of Portland cement. I consider it extremely doubtful that cement which passes the autoclave tests has any particular value above that which passes the standard specification. At least the paper by Mr. Force does not contain evidence to warrant any such conclusion. From many standpoints the proposed test is unreasonable; it is a highly artificial one, and the conditions which are active during the test are never comparable with any which are met with in practice.

It would seem to me that the adoption of the autoclave tests is certain to increase the cost of manufacture and must, without doubt, correspondingly increase the cost to all consumers. If the test does not bring out any desirable qualities which are not revealed by the standard tests, it means the expenditure of a great amount of money by the public without the obtaining of any commensurate results.

For these reasons, I feel that while the paper by Mr. Force is of great value in calling our attention to this sort of a test, it is a dangerous test to rely upon. I also feel that in adopting new requirements affecting so many interests, we should proceed cautiously and make changes only after the results of careful and extended investigations. I certainly would oppose the general use of the autoclave test in specifications for Portland cement, although naturally I would like to see extended scientific investigation in the field to which it pertains.

MR. R. S. GREENMAN.—In studying the paper by Mr. Force on the "Results Obtained with the Autoclave Tests for Mr. Greenman.

Mr. Greenman. Cement" one cannot help but regret that he has not taken this time and place for presenting emphatically and definitely in his paper his reasons for urging the autoclave test for cement. The results of the tests made or quoted by Mr. Force are hardly yet so convincing as to the merit of the test, that one is willing to say that the test does or does not prove that a cement which will pass a proposed requirement in specifications providing for the test, is a better cement for use than one that will not pass the requirements. To each person who has to pass upon the quality of a cement the question has naturally risen—can we secure a better cement by reason of the autoclave test than we now secure under our standard specifications? So to satisfy one's self each one has been compelled to study the question for himself.

The writer of this discussion has for nine months been conducting series of tests according to the specifications and methods suggested by Mr. Force. In his paper Mr. Force presents results of tests on six brands of cement. The writer has tested in the autoclave twenty brands of Portland cement and one puzzolan cement. The results are generally erratic and in the opinion of the writer but one safe conclusion can be drawn; and that is, that the age of the cement when tested has a decided bearing on the result of the test. This point is, I believe, generally conceded by practically all who have made the autoclave tests.

Incidentally it may be said that it seems also that the age of the test pieces within a few months makes no material difference in the result. Now in the "general conditions" of most specifications there is a clause which permits the user of the cement to hold the cement for a 28-day test. If this can be done and there is any doubt as to the early soundness of the cement, why incorporate a new, and as yet a somewhat problematical, test into one's specifications?

It may be that some are taking exception to calling the autoclave test a "problematical" test. The writer has made a careful study of the results of tests made on 97 samples representing 21 brands of cement, and finds that 29 samples failed absolutely, 24 samples gave a lower tensile strength after the period in the autoclave than the normally kept briquettes did,

and while the rest showed an increase in strength, only 28 met the proposed requirement that an increase of 25 per cent in strength be demanded. In other words, 74 per cent of the cement tested failed to meet the latest proposed specifications. Excepting one brand of Portland cement and one brand of puzzolan cement, of which one sample only of each was tested, no brand of cement tested showed a gain in every test except one, and that one brand met the requirement of 25-per-cent increase but six times out of eight. The puzzolan cement increased in the autoclave test to ten times the normal strength. Forty-five of the samples failing in the original test were retested at a later period and 58 per cent of these then showed a gain, but only 27 per cent then made the proposed 25-per-cent increase, or of all samples tested 47 per cent only passed this requirement. Mr. Greenman.

Now the question naturally arises, what is to be gained by requiring this test? The benefit of age can be secured by holding the cement—now what else? Does the autoclave test show that the cement failing to meet the test is not to prove as satisfactory in work as the cement which does pass the test? To answer this it is important to know just why some lots or samples of cement will pass while others fail. The fineness of the cement, the degree of burning, and the ratio of the various elements have been given as reasons. But an examination of all the results of all the tests of the samples tested by the writer fail to show consistent and uniform results in the autoclave tests. Just as one thinks he is about to draw a reasonable conclusion, a test or series of tests will destroy that conclusion. Cements long recognized as standard brands may or may not pass the tests; and yet these cements when passing present standard specifications have been uniformly consistent in actual construction.

While the writer of this discussion does not want at this time to declare himself definitely as to a positive opinion of the value of, and need for, the autoclave test, he does wish to state that he believes that in proposing this test Mr. Force has indirectly stimulated some manufacturers to produce a better cement. It has been noted by the writer that in some few cases, in trying to produce an "autoclave" cement, some

Mr. Greenman. manufacturers have produced cement that has given slightly more uniform results in the standard tests, and a cement which the manufacturer can produce any time when he makes the special effort—a result which may be secured by a strict enforcement of standard specifications, better than by a test of uncertain value and results. No matter whether the autoclave test has merits or not, the presentation of the test has produced some results for which thanks must be given to Mr. Force by the general users of cement.

Mr. Bates. MR. P. H. BATES.—A paper presented at the Sixth Congress of the International Association for Testing Materials by J. Bied, on "Various Chemical Phenomena Encountered in the Course of Industrial Investigations," contains the following statements:

> "Any cement that has stood the hot-water test will never absorb water when treated with steam at a temperature above 140° C. This proves:
>
> "(*a*) That the hydrates of faintly basic aluminates and silicates cannot be formed at this temperature, and that, consequently, they cannot exist except at temperatures below 140° C.
>
> "(*b*) That the strongly basic aluminates and silicates are not attacked by water at this temperature, since if they were decomposed, CaO would be liberated and an absorption of water would take place (because calcium hydroxide does not become hydrated in an atmosphere saturated with steam, except toward the temperature of 550° C.)."

Referring to the above statements and two others, not directly connected with the present matter, the author adds:

> "These three phenomena have been confirmed by Mr. B. Blount, to whom we communicated our observations."

When this was published, the Pittsburgh branch of the Bureau of Standards was engaged in experimenting with the autoclave, and although the temperature obtained in its use was above that mentioned by Bied, it was thought advisable to repeat his work. When this was done, substantially the same results were obtained.

However, in the apparatus used, the hydration is carried on at atmospheric pressure, whereas in the autoclave the pressure recommended is 295 lb. per sq. in. Consequently, the hydration of the dicalcium silicates (it is to be noted that there are four dicalcium silicates with distinct crystallographic prop-

erties) and the calcium aluminates were studied in the autoclave. These were placed in this apparatus so that they were subjected to the influence of the steam alone, that is, they were not placed in the water. In no case have the silicates or aluminates shown signs of hydration. If, however, these materials were allowed to hydrate in water, at room temperatures and atmospheric pressure, for several days, and then placed in the autoclave (subjected to steam action alone), it was noticed that the hydrated portion of the silicate was reduced to an amorphous powder; that the tricalcium aluminate, which normally hydrates almost entirely by absorption of water and crystallization with but slight decomposition into a lower aluminate, continues to hydrate with the formation of large crystals of the hydrated tricalcium aluminate; further, that the $5CaO:3Al_2O_3$ aluminate and the monocalcium aluminate, which normally hydrate by the splitting off of hydrated alumina and the crystallization of hydrated tricalcium aluminate resulting from their decomposition, also show the increased growth of the crystals of tricalcium aluminate and the changing of the apparently colloidal hydrated alumina from a translucent mass to a white amorphous powder. Mr. Bates.

It would appear from the above, therefore, that cements, if made from synthetic silicates and aluminates and placed in the steam in the autoclave after a short preliminary hydration, should show disintegration, as the apparently colloidal material is reduced to a pulverent powder and the crystalline material grows to excessive, frequently microscopical, size.

The statements of Mr. Force in regard to the hydration of the dicalcium and tricalcium silicates are interesting. But the formation of the latter is dependent not only on the fineness of grinding and temperature of burning, but also on the composition of the raw mix. This may be such that there is little likelihood of the possibility of its formation. The analyses (in the nearest whole numbers) of four cements are as follows:

	No. 8.	No. 13.	No. 20.	No. 23.
SiO_2, per cent	20.0	25.0	24.0	24.0
Al_2O_3, per cent	12.0	12.0	15.0	9.0
CaO and MgO, per cent	67.0	62.0	60.0	66.0

Mr. Bates.

These cements showed petrographically that No. 8 contained considerable tricalcium silicate, while No. 13 showed only a little; No. 20 showed none whatever, while No. 23 showed an amount equal to the dicalcium silicate present. An examination of the analyses would show that it would be absolutely impossible practically to burn Nos. 8 and 13 or Nos. 20 and 23 at the same temperature and obtain clinker. As a matter of interest the autoclave test of the neat briquettes in tension and 1:3 two-inch sand cubes in compression showed:

	NEAT BRIQUETTES, LB. PER SQ. IN.		SAND CUBES, LB. PER SQ. IN.	
	Normal.	Autoclave.	Normal.	Autoclave.
No. 8	453	335	875	1860
No. 13	152	159	210	1142
No. 20	168	129	554	1332
No. 23	218	511	380	1449

A comparison of these results brings up Dr. Cushman's statements in regard to the sand-lime brick mortars.[1] The closely comparable results in compression and the widely variant results in tension of the autoclave specimens are very noticeable, and taken in connection with the lime content of the cement, point towards the reaction of the lime set free during hydration with the silica of the sand.

The following results are given as bearing upon the statement in regard as to whether the autoclave test produces in a short period a normal hydration. Is it an accelerated test in which the phenomenon of hydration is identical with that which would take place under normal conditions? If such is the case, a specimen placed in water for a definite period and then in the autoclave, or placed in the autoclave at the end of 27 hours and then in water for the same period, should show a greater strength than one placed in water alone, since there would be obtained the normal strength (hydration) plus the autoclave strength (hydration). The two cements were tested (neat

[1] This statement refers to Mr. A. S. Cushman's discussion "by letter" of Mr. Force's paper, which appears on pp. 781-785.—ED.

briquettes) at the periods noted after the conditions of aging as shown: **Mr. Bates.**

CONDITIONS OF AGING.	CEMENT A.				CEMENT B.			
	24 hr.	7 days.	28 days.	90 days.	24 hr.	7 days.	28 days.	90 days.
Normal aging	115	437	636	738	363	639	683	690
In autoclave at end of 24 hr. and then in water until end of period shown	444	515	606	753	418	378	469	688
In water until end of period shown and then in autoclave	...	406	788	814	...	473	503	468

Cement A is a high-silica cement which seldom gives 1:3 sand briquettes passing the 7-day requirement of the standard specifications; cement B is a highly aluminous, very low-silica cement which gives high strength at 7 days and but little gain afterward. The results of the test of these two widely different cements as shown above, particularly at the end of 90 days, point very strongly to the fact that the hydration in the autoclave is abnormal.

THE SECRETARY.—The remarks I desire to offer are intended to be of a somewhat general nature rather than restricted to the particular test under discussion. It seems to me that any one disposed to advocate for adoption in specifications a new test of a drastic nature, should feel it incumbent upon him first to establish, or to have established for him, within reasonable limits of certainty, the reliability of such a test; and that it ought not to be made incumbent on individual testing engineers to prove or disprove its value. It would seem that the author of such a test should be the first to welcome its critical investigation by a duly appointed body of which he would naturally be a member, and that conclusions as to the merits of the test should be held in abeyance pending the report of that body. Individual testing engineers would thus be relieved of the responsibility of conducting investigations separately at a great aggregate sacrifice of time and energy in seeking to do individually and with much duplication and overlapping that which can be done much more effectively and authoritatively by a joint body. **The Secretary**

[On motion of Mr. Robert W. Lesley, and with the approval

The Secretary. of the author, Mr. Force's paper was accepted, with the understanding that it would be printed in the Proceedings, and that it would be referred to Committee C-1 on Standard Specifications for Cement.]

Mr. Hanna. MR. W. C. HANNA (*by letter*).—I have been very much interested in the autoclave tests conducted by Mr. Force, and have made a large number of such tests in order to become acquainted with the method of testing and to learn the value of the test.

From these tests and observations of methods of manufacture, I consider the autoclave test valuable when applied to neat Portland cement. It may be that there should be changes made in the specifications drawn up by Mr. Force, and it is very probable that numerous cements which would give good results in practice will be rejected by the autoclave test.

I have had under observation a pat made from cement which would fail in the boiling test in less than one hour boiling. The pat has been stored in water and air at about 70° F. for the past eight years, and I have noticed no checks or cracks up to this time. Probably this cement would have given good results in practice, yet it is difficult to find an engineer who would risk using a cement which is not sound in the boiling test.

Ten years ago cements unsound in the boiling test were not uncommon, and much cement of this class has been used which seems to have given satisfaction so far. No one knows concerning the future, however. We are building for hundreds of years duration, and any test that will point out a cement which will be more durable than the ordinary cement, is valuable.

In order to manufacture cement which will pass the autoclave specification, good raw materials are required, and care in the manufacture. This will raise the cost of manufacture, and, of course, the consumer should pay for it. Regrinding will help some cements to pass autoclave tests, while with others I have noticed no change. A reasonable amount of storage seems to help some cements to meet the requirement, yet with many cements the storing reduces the normal strength to such an extent that even with tremendous gain, the strength will be

less than 400 lb. after removal from the autoclave. Cements which pass the autoclave test weigh less than when placed in the autoclave, and the percentage of expansion is usually about 0.3 per cent. This is also true of cements of low strength, but which are sound in the autoclave. Furthermore, some cements which pass the standard specifications of the Society will disintegrate in the autoclave. **Mr. Hanna.**

MR. A. S. CUSHMAN (*by letter*).—The following is an excerpt from the report of the writer on the proposed autoclave test for Portland cement to the Association of American Portland Cement Manufacturers by authorization of that Association.[1] **Mr. Cushman.**

Historical Data Relating to the Autoclave Test, Including Opinions of German Authorities in Regard to It.—As far as we have been able to determine, the high-pressure steam test on Portland cement was first recommended in Germany by Doctor Erdmenger in 1881. The Erdmenger test was fully investigated by some of the leading German authorities on cements and was rejected by them as inadequate and misleading. This is clearly shown in the translations from letters addressed to the Secretary of the Association of American Portland Cement Manufacturers.[2]

In commenting on the test, Doctor Dyckerhoff states as follows:

"As early as 1881 Doctor Erdmenger recommended in Germany a high-pressure steam test of Portland cement, with a view to testing its constancy of volume. This was rejected by the commission on volume constancy in the Royal Bureau of Material Testing (Kgl. Materialprufungsamt), their opinion being based on the fact that such a test had no bearing upon the problems of building construction. At the present time in Germany we consider the high-pressure steam test as being wrong and misleading."

Professor Gary of the Royal Bureau of Material Testing writes as follows:

"Permit me to inform you that the high-pressure steam test was first recommended by Doctor Erdmenger in our country but was never put to

[1] *Bulletin No. 28*, 1913, Proc. Assoc. Am. Portland Cement Mfrs.

[2] The letters from which the above citations are made refer also to other subjects except those under discussion in this paper. It therefore did not seem advisable to publish the letters in full. They are in the possession of the Secretary of the Association of American Portland Cement Manufacturers, and the author is assured that any one wishing to verify them in relation to the general context of the letters will be extended every opportunity to examine them in the original.

Mr. Cushman. practical use on a large scale, because it was soon discovered that this test was even less adapted to distinguish useless cements from useful cements than the usual methods of determining constancy of volume."

A careful study of all the available data in connection with the historical development of the high-pressure steam tests as reported in the transactions of the International Association for Testing Materials shows very clearly that, as a quantitative acceleration test the use of high-pressure steam has been generally condemned by leading authorities, because it has been found to lead to erratic and inconsistent results.

The Influence of High-Pressure Steam on the Hardening of Portland Cement.—As the result of numerous experiments with the autoclave test, it is now well known that Portland cements, when made into neat briquettes and allowed to obtain their initial set in a damp closet, may behave in different ways when subsequently heated in a high-pressure steam digester. They may increase in strength, remain unchanged, or deteriorate partially or to the point of falling to pieces. In attempting to account on purely theoretical grounds for this difference of behavior, the following important question naturally presents itself: *Is this difference of behavior a mark or measure of quality, efficiency or condition in a given cement?* If the action of superheated steam is merely to carry out in a few minutes the hardening reactions which would naturally take place in time under service conditions, the question would have to be answered in the affirmative. If, however, the action of superheated steam is to induce a new set of reactions, leading to an artificial, superinduced bond which would never under any circumstances take place under normal service conditions, the question must be answered in the negative.

It is a very well-known fact that if lime and silica in certain proportions are ground together in a slightly damp condition, molded into briquettes and subjected to the action of high-pressure steam, a very strong bond is formed. The reactions induced by the action of the high-pressure steam are the basis of the sand-lime brick industry. Now, a mixture of lime and silica merely ground together in a damp condition would have no hydraulic properties whatsoever, and would never set or develop strength under the conditions which govern the setting and har-

dening of Portland cements. The sand-lime brick bond has nothing whatsoever to do with a hydraulic bond, and the reactions which account for it are induced entirely under the action of high-pressure steam carried on for a few hours. Unquestionably Portland cement, after being mixed with water, formed into briquettes and allowed to form the first hydraulic bond, contains both hydrated lime and to some extent reactive silica. It would therefore be expected that on subsequently subjecting it to the action of high-pressure steam, the sand-lime or silica-lime bond would be formed, which might or might not reinforce the natural hydraulic bond already formed. An excellent and comprehensive research on the bond formed between lime and silica under the action of high-pressure steam, is to be found in a paper published by S. V. Peppel, entitled "The Manufacture of Artificial Sandstone or Sand-Lime Brick," Bulletin No. 5, Geological Survey of Ohio, 1906.[1] In this excellent paper Peppel has shown that the strength of the bond formed in the autoclave depends on a number of factors, in which may be included the reactive condition of the lime and silica present. From a careful study of this paper and the application of the principles which it develops, to the present subject under consideration, it is indicated that the action of the autoclave test for Portland cement is merely to produce in addition to the ordinary hydraulic bond a silica-lime bond which can only be produced under the action of high-pressure steam. If this is true, it at once becomes apparent that the autoclave test is not a rational one and should not be used as a method of judging the behavior in construction work of a given brand of Portland cement. Mr. Cushman.

The Autoclave Test in Its Relation to the Development of Compressive Strength of Different Brands of Cement.—While theoretical considerations are important in judging the value of any test, its real usefulness must rest in the ability to clearly show those qualities which make for better concrete in both short and long periods. In order to determine whether the autoclave test as proposed was able to distinguish between cements which develop their bond normally and properly under service conditions, the Institute of Industrial Research undertook a

[1] See also a very recent treatise entitled "Sand-Lime Brick and Artificial Sandstones in the Philippines," by Cox, Reibling and Reyes, *Philippine Journal of Science*, Vol. VII, No. 5, Sec. A.

Mr. Cushman. systematic investigation. A number of different brands of standard Portland cements were purchased in the open market and tested both by the standard methods and by the autoclave test. Out of all these brands tested, four were selected for the purpose of the investigation. One of these four cements absolutely failed under the conditions of the autoclave test, to the extent that the briquettes made of it disrupted and fell to pieces in the autoclave. Another one showed deterioration, while two of the cements passed the most severe specifications for the auto-

TABLE IV.—RESULTS OF TESTS TO DETERMINE THE RELATIVE CRUSHING STRENGTHS OF CONCRETE MADE FROM CEMENTS WHICH PASSED AND CEMENTS WHICH DID NOT PASS THE AUTOCLAVE TEST.

(RESULTS AVERAGE OF FIVE TEST PIECES)

Sample No.	15 (Passed)	16 (Passed)	20 (Failed)	21 (Failed)
TENSILE STRENGTH. (lb. per sq. in.)				
24 hours	351	296	33	407
Autoclave	455	403	0	241
COMPRESSIVE STRENGTH 6-IN. CYLINDERS. (lb. per sq. in.)				
At end of 3 months	1688	1768	1727	1454
First crack	1444	1661	1609	1339
At end of 6 months	1900	1936	1973	1875
First crack	1776	1754	1867	1777
At end of 1 year	2230	2253	2634	2080

clave test and increased more than 25 per cent in strength. A large number of 6-in. cylinder test pieces were then made up from each of these selected cements. The test pieces were made from a 1:2:4 mixture, using Potomac River sand and crushed trap rock screened to pass a 1-in. screen. All sets of test pieces were made up as nearly as possible under exactly the same conditions. After the test pieces had obtained their final set, they were taken out of doors and laid in a sand bed in the form of a tesselated pavement flush with the surface of the ground. They were thus exposed to normal service conditions which Portland-cement concrete may be expected to meet. At 3 and 6-month periods a set of 5 test pieces was removed from each lot and tested under compression in the usual way in a Riehlé

150,000-lb. testing machine. These specimens are at the present time not quite one year old, but an inspection of the results for the 3 and 6-month periods, which are given in Table IV, shows that

Mr. Cushman

TABLE V.—RESULTS OF TESTS TO DETERMINE THE RELATIVE TENSILE STRENGTHS OF NEAT AND MORTAR BRIQUETTES MADE FROM CEMENTS WHICH PASSED AND CEMENTS WHICH DID NOT PASS THE AUTOCLAVE TEST.

(TENSILE STRENGTH, LB. PER SQ. IN.)

Sample No.	34	40	35	42
NEAT BRIQUETTES				
24 hours	215	348	310	200
24 hours, autoclave	302	460	182	46
Percentage increase or decrease	+40.5	+32.2	−41.3	−82.0
6 months in water	695	719	685	....
6 months in water, autoclave	484	507	501	....
Percentage decrease	−30.4	−29.5	−26.7	....
6 months in air	810	728	732	....
6 months in air, autoclave	568	695	471	....
Percentage decrease	−29.9	− 4.5	−35.6	....
7 days in water, 6 months in air	801	775	787	....
7 days in water, 6 months in air, autoclave	582	573	492	....
Percentage decrease	−27.3	−26.1	−37.5	....
1:3 STANDARD SAND BRIQUETTES.				
24 hours	49	78	103	44
24 hours, autoclave	128	139	112	35
Percentage increase or decrease	+161.2	+78.2	+ 8.7	−20.4
7 days	157	238	205	220
7 days, autoclave	140	148	183	357
Percentage increase or decrease	−10.8	−37.8	−10.7	+62.3
6 months in water	243	327	349	....
6 months in water, autoclave	169	345	245	....
Percentage increase or decrease	−30.4	+5.5	−30.0	....
6 months in air	336	475	502	....
6 months in air, autoclave	205	215	250	....
Percentage increase or decrease	−39.0	−54.8	−50.0	....
7 days in water, 6 months in air	457	....	550	....
7 days in water, 6 months in air, autoclave	251	....	285	....
Percentage increase or decrease	−45.1	....	−48.2	....

there is little or no difference to be observed between the strength developed by any of the samples of cement, irrespective of whether they passed or failed under the autoclave test. As a

Mr. Cushman. matter of fact, the maximum figure for the 6-month period, as the average of 5 test pieces, is represented by the cement which gave the worst result of the two which failed under the autoclave test. As far as these tests have gone, it is shown that the autoclave test is not able to distinguish between the strength-developing qualities of cements up to 6 months, under normal exposure to out-of-door conditions.[1]

The Autoclave Test in Its Relation to the Development of Tensile Strength as Measured by the Standard Briquettes.—In addition to the work described in the last paragraph, a very large number of tensile strength test pieces have been prepared in the laboratories of the Institute of Industrial Research for further investigation of the autoclave test. Autoclave tests made on neat and 1:3 briquettes aged in various ways for periods up to 6 months and prepared from two cements which originally passed and two cements which originally failed under the autoclave test, gave erratic results. In general, however, the autoclave test made on all briquettes over 24 hours old, whether stored in air or water, or part of the time in air and the rest of the time in water, showed a decrease in strength as compared to the ordinary standard tests. The results upon which this statement is based are shown in Table V.

Mr. Fuller. MR. J. W. FULLER, JR. (*by letter*).—In connection with the autoclave test, I have obtained samples of cement from various plants throughout the United States and Canada, operating by different processes and on different materials, and have had these samples subjected to the autoclave test with the results shown in Table VI, the values given in each case being the average of three tests.

These plants, situated in widely different localities, embrace practically all the different materials used in cement manufacture, and are all able to produce autoclave cement by extremely fine grinding of their materials, and of course by the usual careful attention to the proper proportioning and burning of their mixtures. The data are sufficiently exhaustive to justify the opinion that any other plant can do the same thing.

It is natural, of course, that some of the manufacturers

[1] Since the above paragraph was written the results of the one-year test have become available and are included in Table IV.

will be put to considerably more expense to manufacture autoclave cement than others, but there is no question that there is also a wide difference in the cost of manufacturing the standard Portland cement. Mr. Fuller.

In connection with this investigation, a total of 399 different samples of cement were subjected to the autoclave test, and as nearly all of these samples were representative bin samples, the tests actually cover about one million barrels of

TABLE VI.—RESULTS OBTAINED WITH AUTOCLAVE TESTS.

Plant.	Location.	Process.	Materials.	Fineness, per cent passing sieves.		Tensile Strength.			Expansion, per cent.
				100	200	24 hr., neat, lb. per sq. in.	Force Autoclave, lb. per sq. in.	Gain, per cent.	
A	California...	Dry.....	Limestone and clay	95.1	84.0	400	645	61.5	Less than 0.5
A	California...	Dry.....	"	95.0	84.0	418	781	86.8	Less than 0.5
A	California...	Dry.....	"	95.1	84.1	334	662	98.1	Less than 0.5
A	California...	Dry.....	"	95.1	83.6	273	625	129.2	Less than 0.5
B	Washington.	Dry.....	Limestone and shale	95.0	84.3	400	840	110.0	Less than 0.5
B	Washington.	Dry.....	"	96.8	86.5	370	810	118.9	Less than 0.5
C	Kansas.....	Semi-wet	Limestone and clay	95.3	85.1	460	850	84.8	Less than 0.5
D	Michigan...	Dry.....	Limestone and shale	95.8	85.8	430	870	102.3	Less than 0.5
E	Pennsylvania	Dry.....	Cement rock and limestone	94.9	84.8	420	930	121.4	Less than 0.5
E	Pennsylvania	Dry.....	Cement rock and limestone	95.5	85.6	345	790	129.0	Less than 0.5
F	Canada.....	Wet.....	Limestone and clay	95.0	84.5	300	600	100.0	Less than 0.5

cement. Over three hundred samples passed the autoclave test in freshly ground condition, and all the remainder, with the exception of three samples, passed on retests after a little aging. These three samples failed on the standard soundness test originally, and while aging for a month enabled them to then meet the steam and boiling tests perfectly, although after a year's aging they still failed to meet the autoclave test requirements.

Mr. Fuller. I would not advise having the autoclave test incorporated in the general specifications for Portland cement, for I do not think it practicable at this time, or even necessary, to have all the cement manufactured in the United States pass the autoclave test, but there should be a separate specification for autoclave cement.

All the cement, when freshly ground, does not uniformly always pass even the ordinary soundness test of the present standard specifications, and the autoclave test is of course still more severe. I do think, though, that autoclave cement should be specified for certain work, just as, for instance, stay-bolt iron is specified in preference to ordinary bar iron for boilers and certain other classes of work.

In this stand I am moved by the following considerations: Years ago, when coarse grinding was in vogue in cement manufacture, it was extremely difficult to obtain cement which could pass the ordinary soundness or boiling test. By finer grinding, sound cement was achieved—an admittedly better product than the former. I find from practical experience that, with operating conditions favorable to the manufacture of a product which passes the soundness and other standard specifications but fails on the autoclave test, increasing the fineness of both the raw materials and the clinker, for instance, from 80 per cent through a 200-mesh sieve to 85 per cent through a 200-mesh sieve, will yield a product which will also then pass the autoclave test, in addition to the other requirements.

In one case within my observation a plant had been grinding the raw material to a fineness of about 80 per cent (averaging 80.4 per cent) through the 200-mesh sieve. The mixture was normal, as was also the burning. The clinker was being ground to about the same fineness, and the resulting cement under these conditions, while passing perfect soundness tests and exceeding the standard specifications in tensile strength, uniformly failed on the autoclave test, the autoclave briquettes "breaking in the clips."

The necessary steps were then taken to secure a greater degree of pulverization, the fineness on the raw side being increased to 95 per cent through the 100-mesh and 84.6 per cent through the 200-mesh sieve, the composition of the mixture

remaining the same. The bin of cement resulting from two days' run of the mixture of the fineness indicated showed the following results: Mr. Fuller.

FINENESS.		SOUNDNESS.		NEAT,	FORCE,	PERCENTAGE
No. 100.	No. 200.	STEAM.	BOIL.	24 HOURS.	24 HOURS.	GAIN.
94.4	84.2	O.K.	O.K.	340 lb.	630 lb.	85.3

With finer grinding yielding a sound and admittedly better cement, and extreme fineness as a necessary factor for the achievement of perfection of any chemical reaction, the fact that still finer grinding will yield autoclave cement, to my mind entitles autoclave cement to the benefit of the doubt as to whether it is a better product than one which fails to pass the autoclave test.

Most cement manufacturers have had the experience, at one time or another, of cement failing to meet the ordinary soundness test when freshly ground, but passing the test readily after aging for a greater or less period in the stock-house bin, and the cement in this aged condition, then passing the soundness test, is generally considered to be an improved product.

I have at hand a great many tests bearing on this point in connection with the autoclave test, one of which, bin "A," will suffice to bring out the point in mind. The bin readily passed all standard specifications, the autoclave results being as shown in Table VII.

TABLE VII.—TESTS SHOWING EFFECT OF AGING.

Bin.	When ground.	When tested.	Steam Test.	Boiling Test.	Tensile Strength		
					24 hr., neat, lb. per sq. in.	Force, Autoclave, lb. per sq. in.	Loss or Gain, per cent.
A	Feb. 17, 1913..	Feb. 17, 1913..	O. K.	O. K.	400	Disintegrated	.....
A	Feb. 17, 1913..	Feb. 24 1913..	O. K.	O. K.	400	Disintegrated	.....
A	Feb. 17, 1913..	Mar. 3, 1913..	O. K.	O. K.	400	270	−32.5
A	Feb. 17, 1913..	Mar.10, 1913..	O. K.	O. K.	400	390	− 2.5
A	Feb. 17, 1913..	Mar. 17, 1913..	O. K.	O. K.	400	580	45.0

Mr. Fuller. This cement, bin "A," on March 17 would hardly be considered inferior to this same cement on February 17; in fact, even on general principles, it would be considered to be improved, if anything. On March 17 it was autoclave cement, while on February 17 it was not.

Of the great number of tests which I have had so far conducted, there has not been an instance where cement that originally passed the standard specifications, which included the soundness test fresh from the mills, did not eventually also pass the autoclave test by aging from 1 to 6 months, though it did not originally pass the autoclave test.

Mr. Force. MR. H. J. FORCE (*Author's closure by letter*).—My paper was presented to the Society for the purpose of calling the attention of engineers and manufacturers to the two distinct types of cement now on the market, and to give the results of each as tested by the autoclave.

Both of these types passed the specifications adopted by the American Society for Testing Materials, but when subjected to the autoclave test, one showed a tensile strength of 600 lb. per sq. in. while the other completely disintegrated. The first type showed an expansion of 0.15 per cent while the other showed an expansion of between 4 and 6 per cent.

It was thought that the presentation of my paper at the annual meeting of the Society would stimulate further research as to the value of the autoclave test,[1] and it was assumed that research along this line would be welcomed by the manufacturers. No one, I am sure, can contemplate the situation which we have been trying to investigate, without being impressed by the adverse, antagonistic interests involved. Surely, it is as legitimate for the consumer to study the methods by which cement is manufactured, as it is for the manufacturer to study the treatment which his cement receives in service.

In view of certain concrete failures it cannot be denied that the subject is a pressing one, and that there is need of a thorough investigation of the concrete problem by the manu-

[1] By vote at the last annual meeting Mr. Force's paper on "Results Obtained with the Autoclave Tests for Cement," was accepted with the understanding that it would be printed in the Proceedings and that it would be referred to Committee C-1 on Standard Specifications for Cement. Committee C-1 is expected to present to the Society, in due course, its report on this subject.—ED.

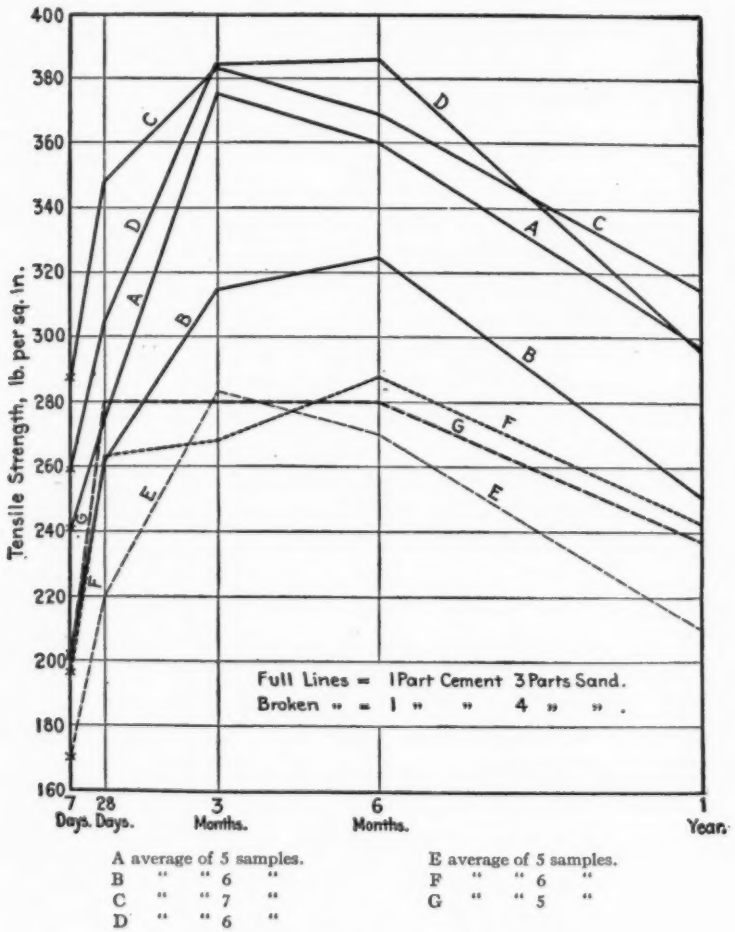
facturers and the consumers. While the papers that have been presented in the discussions on my test are voluminous, I am disappointed in that, as a rule, they fail to account for the differences existing between autoclave and non-autoclave cement. Two exceptions, however, may be noted. The papers by Mr. Wig and Mr. Bates show that an autoclave cement is the more uniform and gives higher results when subjected to compression. They fail, however, to offer any explanation of their results. Mr. Force.

Some manufacturers have insisted that a cement which fails under the regular hot test would give good results in service. The results obtained by Mr. Wig do not so indicate. Samples tested in our own laboratory at Scranton show similar results; many of them went to pieces in a few months when kept in air, while other specimens which were kept in water lost one-half of their compressive strength at the end of one year. It is very likely that many samples of this type of cement would stand a hot test at 150° F., whereas at 212° F. these samples would fail. The question naturally arises: If the cement was bad when tested at 150° F., would the small difference of 62° F. necessarily pass a cement of good and lasting quality?

The objection has been made that the results obtained in the autoclave test are erratic. An inspection of the tables in my paper on mills Nos. 1 to 5 does not sustain this objection. The results in mills Nos. 1 and 2 are exceptionally uniform, while mills Nos. 3, 4 and 5 show a wide variation in the different samples, indicating an erratic cement, probably due to poor mill control and to the quality of the raw material. The fault lies in the cement and not in the method of testing it.

It has been hinted at times that certain brands of cement are superior to others because they are manufactured from natural rock, which requires very little or no addition of either high-lime stone or shale. Where rock of this kind is not available, and the addition of high-lime stone or shale is necessary, the process of manufacture must necessarily be somewhat changed. If the particles of raw material are of considerable size or if thorough admixture of the raw material is not attained, complete chemical reaction cannot take place in the short space of time the material is in the kiln. For this reason the manufacturers who do not use a natural rock must grind their raw

Mr. Force. material finer than their competitors who use a natural rock. It is evident that it will cost the first class more to produce an autoclave cement than it will the second class.



A average of 5 samples.
B " " 6 "
C " " 7 "
D " " 6 "

E average of 5 samples.
F " " 6 "
G " " 5 "

FIG. 5.—Tension Tests of 1:3 Briquettes.

This can be best illustrated by referring to Fig. 5, which shows four different brands of cement of 1:3 sand, tested to one year, and three different brands of cement of 1:4 sand, tested to one year. These tests are the average of the number of samples

indicated in the figure. The briquettes were made up according to the standard specifications of the Society. In the 1:3 briquettes, samples A and B are cement in which the addition of high-lime stone was necessary. In the case of sample B, the percentage of high-lime stone which was added to the rock from the quarry amounted at times to as much as 30 per cent, while in the case of sample A the percentage was considerably smaller. Both of these samples failed to pass the autoclave test. Samples C and D were made from natural rock which required no addition of high-lime stone. Sample C passed the autoclave test while sample D failed, although it stood the test much better than either sample A or B. The raw material from which samples A, B and D were made were ground to the same degree of fineness, while the raw materials used for sample C were more finely ground, thereby producing an autoclave cement. In the 1:4 mix, sample E was from the same mill as sample B, and also failed to pass the autoclave test. Samples F and G were made from natural rock which required no addition of high-lime stone. Both of these samples passed the autoclave test and showed higher results than sample E at all periods except at the end of three months. Mr. Force.

From these results it is quite evident that if the manufacturer who finds it necessary to use a large percentage of high-lime stone rock or shale wishes to produce autoclave cement, he must grind his raw material finer, in order to get a thorough admixture. Later tests on samples from the same mill which furnished samples E and B have proven this to be the case. New machinery has recently been installed in this mill, and the raw materials are ground much finer than formerly. The product of this mill now passes the autoclave test and results so far have shown a tensile strength similar to that of sample C. It is also noted that the drop in tensile strength on cements which are not autoclave is much sharper from six months to a year, indicating that retrogression is more rapid in non-autoclave cement.

As there is a wide difference between some autoclave cements and some non-autoclave cements, it would appear that engineers and consumers would be justified in using but one of

Mr. Force. these two types, especially when it is a noted fact that from 50 to 60 per cent of all the cement manufactured in the Lehigh Valley District for the past two years would well meet the requirements of the autoclave test. Experimental data to date indicate that autoclave cements are more uniform, are higher in compressive and tensile strength, and are more constant in volume; the data referred to being the tensile strength tests recorded in my paper, those shown in the accompanying Fig. 5, and the results of compression tests reported by Mr. Wig in his discussion.

The results obtained by Mr. J. W. Fuller, Jr., on the autoclave test with a number of brands of cement from different parts of the United States, compare very favorably with my results. Mr. Fuller is not a consumer, but is a large manufacturer of Portland cement and one well qualified, in my judgment, to give an opinion upon this important product. It is evident from the results obtained by Mr. Fuller, as well as our own, that the requirements of the autoclave test can easily be met.

For the benefit of those who are not familiar with this test, that portion of the specifications as adopted by the Lackawanna Railroad Co. and others is quoted as follows:

EXTRACT FROM SPECIFICATIONS FOR PORTLAND CEMENT OF THE DELAWARE, LACKAWANNA & WESTERN RAILROAD CO.

1. *Definition.*—The cement shall be the product obtained by finely pulverizing clinker produced by calcining to incipient fusion, an intimate mixture of properly proportioned argillaceous and calcareous substances, with only such additions subsequent to calcining as may be necessary to control certain properties. Such additions shall not exceed 3 per cent, by weight, of the calcined product.

2. *Specific Gravity.*—The specific gravity of the cement shall not be less than 3.10.

3. *Fineness.*—Ninety-five per cent of the cement, by weight, shall pass through the No. 100 sieve, and 80 per cent of the cement, by weight, shall pass through the No. 200 sieve.

4. *Time of Setting.*—The cement shall not acquire its initial set in less than 1 hour and must have acquired its final set within 10 hours.

5. *Soundness: Force Autoclave Test.*—Three neat briquettes to be made up in the usual manner and allowed to remain in the damp closet for 24 hours. At the expiration of that time, the briquettes are to be removed from the

molds and placed in the autoclave, sufficient water being added to partly or wholly cover the briquettes. The autoclave is then closed, the burners being of sufficient size to raise the pressure to 295 lb. in not more than 1 hour. The pressure of 295 lb. shall be maintained for 1 hour longer, or a total time of 2 hours. The pressure is then to be gradually released, the briquettes taken out and placed in the moist closet, where they shall be allowed to remain for 1 hour. At the end of that time they are to be broken in the standard cement testing machine in the usual manner. The average tensile strength of the three briquettes taken from the autoclave must show a tensile strength of not less than 500 lb. per sq. in. They must also show an increase of not less than 25 per cent over the average tensile strength of three briquettes broken at the end of 24 hours. A bar of neat cement, 6 in. long by 1 in. square, shall be made up at the same time the briquettes are made. This expansion bar to remain in the moist closet for 24 hours and to be removed along with the briquettes and tested with the briquettes in the autoclave, as indicated above. After one hour in the moist closet, this expansion bar shall not show an expansion greater than 0.5 per cent. **Mr. Force.**

6. *Tensile Strength.*—The minimum requirements for tensile strength for briquettes 1 in. square in section shall be within the following:

NEAT CEMENT.

AGE.	STRENGTH.
24 hours in moist air	200 lb.
7 days (1 day in moist air, 6 days in water)	500 "
28 days (1 day in moist air, 27 days in water)	600 "

ONE PART CEMENT, THREE PARTS SAND.

AGE.	STRENGTH.
7 days (1 day in moist air, 6 days in water)	250 lb.
28 days (1 day in moist air, 27 days in water)	375 "

The average of the tensile strengths developed at each age by the briquettes in any set made from one sample is to be considered the tensile strength of the sample at that age. Any results that are manifestly faulty will not be included. The sand briquettes will be thoroughly tamped in the molds by using an iron die to fit inside the sand briquette mold; this die to be struck a number of blows with a wooden mallet.

7. *Composition.*—In the finished cement, the following limits shall not be exceeded:

	PER CENT.
Loss on ignition for 20 minutes	4
Insoluble residue	1
Sulphuric anhydride (SO_3)	1.75
Magnesia (MgO)	4

Mr. Force. 8. *Insoluble Residue.*—The insoluble residue shall be determined on a 1-gram sample which is digested on the steam bath in hydrochloric acid of approximately 1.035 specific gravity until the cement is dissolved. The residue is filtered, washed with hot water, and the filter-paper contents digested on the steam bath in a 5-per-cent solution of sodium carbonate. The residue is then filtered, washed with hot water, then with hydrochloric acid, approximately of 1.035 specific gravity, and finally with hot water. then ignited and weighed. The quantity so obtained is insoluble residue,

OBSERVATIONS ON THE TESTING OF SAND.

By W. B. Reinke.

For any proposed piece of concrete construction, engineers as a rule, and rightly so, are very willing to inspect or have inspected the cement to be used, accepting as a matter of course the necessary expenses involved.

When the subject of sand-testing is brought up, however, the reply is generally, "Oh! we don't care about that," or "We will have samples sent to this office and look at them to determine their value." As a rule, they are quite satisfied that they have taken care of everything needed to produce a good concrete when they write strict specifications for the cement. They "pat themselves on the back," look pleased and forget about the sand, overlooking the fact that this material is used as found in its natural state with every chance for wide variation in quality and that it forms from two to four times as much of the concrete as does the cement.

Few specifications contain definite requirements as to the quality of sand, the subject being dismissed with a general clause, providing that it must be clean, sharp and free from loam. As generally interpreted, the word loam includes clay matter and finely divided silica. Experience has shown that for the best results, work sand may be too clean, that it need not necessarily be sharp, and that under some conditions a certain amount of clay or finely divided silica is advantageous. The quality of sand is, as a rule, judged by the eye and touch. No attention is paid as to what the mineral constituents composing it may be; what granulometric analysis it may have; whether it may or may not contain minerals in a combined or free state, which will make it harmful to the concrete; whether it is so finely divided as, through the formation of colloids or otherwise, to retard or inhibit hardening of the concrete; or whether it may contain soluble alkalies, which may hasten the set of the cement to such an extent that the initial set is broken while it is still in the mixer and the whole mass becomes for a period, as

far as setting is concerned, so much inert or at best feebly cementitious material.

For the last two years the company with which the writer is associated has investigated the reason for failure of a number of pieces of concrete masonry to harden properly. In some cases where the forms had been removed, the concrete was showing signs of yielding to stress of its own weight, raising a question as to its ultimate stability. In others the hardening was being retarded, thus delaying the removal of forms.

From knowledge gained in these investigations, as well as results of many tests of sands carried on in our laboratory, certain salient features and characteristics of sands in general have been brought so forcibly to our notice as to make it seem imperative to pay quite as much attention, if not more, to the inspection of sand entering into any construction, as is paid to the inspection of cement.

It, therefore, seems advisable that a committee of this Society be appointed to prepare definite specifications for sand and uniform methods for testing it.

While the testing of sand is becoming more general, the work is being done under more or less tentative specifications prepared by individuals; no two laboratories seem to apply the same tests or use identical methods, the tests being carried out differently by each investigator. Most tests are made on samples delivered to the laboratories, no opportunity being allowed for the examination of the deposit or the selection of truly representative samples. The reason for this is chiefly one of dollars and cents, and since the condition obtains, the laboratory must do the best it can with the sample submitted.

The following are the usual tests to which samples of sand submitted for testing are subjected, but it is rarely that all are employed in any one laboratory:

1. Determination of the percentage of moisture;
2. Determination of the percentage of voids;
3. Granulometric analysis;
4. Determination of the percentage of silt;
5. Chemical analysis to determine silica and content of clay matter;

6. Loss on ignition;
7. Volume of mortar from a given amount of sand and cement;
8. Comparative tension tests of mortars made from work sand and standard Ottawa sand, using identical cement and only sufficient water to produce normal consistency.

At this point it is hardly necessary to call attention to the fact that although tension tests are used for testing sands, this practice would seem to be altogether arbitrary and has grown out of the long-established custom of making tension tests of cement, which, as every one knows, was instituted only on account of convenience of having small portable inexpensive machines, which could be carried from one place to another without much trouble.

We would suggest that all comparative sand tests be made on cubes or cylinders subjected to compression, as concrete itself is rarely subjected to tension. This practice has been adopted in Germany, where tension tests of cement and sand mortars have been largely eliminated.

To the foregoing tests should be added several not usually carried out:

1. Microscopic examinations, which need not necessarily be exhaustive;
2. The effect on strength developed by the use of different cements;
3. Permeability of resulting mortars;
4. Weight per cubic foot as rece ved and dried;
5. Determination of the amount of organic matter contained;
6. Tension or preferably compression tests on wet mortars, having the same consistency as used in the work.

This last test the writer believes to be the most important, and one to which all sands should be subjected. To the best of our knowledge, however, it is not generally used by laboratories other than the one with which the writer is connected.

The general practice in testing sands is to compare work sand with standard Ottawa sand, using the same cement, the briquettes being made from mortars having normal consistency,

TABLE I.—SHOWING LOSS IN TENSILE STRENGTH FOR EACH PERCENTAGE OF WATER REQUIRED TO BE ADDED TO MORTAR.

NORMAL CONSISTENCY.

Period.	Ottawa Sand.			Work Sands.																			
	9.2 per cent Water, 100 Tests.			12 per cent Water, 18 Tests.			12–13 per cent Water, 30 Tests.			13–14 per cent Water, 16 Tests.			14–15 per cent Water, 12 Tests.			15–16 per cent Water, 8 Tests.			Over 16 per cent Water, 16 Tests.		
	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.
72 hours	245	160	192	278	110	200	168	62	105	150	57	80	80	48	52	58	40	43	48	40	43
7 days	384	233	301	420	180	273	288	176	258	340	97	215	265	99	170	262	89	158	240	73	129
28 days	502	300	410	605	270	388	462	277	377	493	165	325	455	133	262	321	183	251	340	129	187

WORK CONSISTENCY.

Period.	Ottawa Sand.			Work Sands.																			
	13.8 per cent Water, 64 Tests.			17–18 per cent Water, 8 Tests.			18–19 per cent Water, 6 Tests.			19–20 per cent Water, 12 Tests.			20–21 per cent Water, 10 Tests.			21–22 per cent Water, 8 Tests.			22–23 per cent Water, 6 Tests.			Over 23 per cent Water, 10 Tests.		
	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.
72 hours	190	100	140	115	80	92	92	80	86	67	58	63	63	52	55	50	18	30	30	12	23	31	10	18
7 days	280	178	235	236	170	208	210	140	180	187	107	146	150	110	128	158	100	122	125	95	111	120	58	92
28 days	374	230	316	371	292	310	300	239	279	342	186	267	270	180	229	261	183	220	250	175	215	202	143	173

TABLE II.—SHOWING LOSS IN TENSILE STRENGTH FOR INCREASED PERCENTAGE OF SAND PASSING NO. 40 SIEVE.

NORMAL CONSISTENCY.

Period.	Ottawa Sand, 100 Tests.			Work Sands.													
				Up to 10 per cent, 10 Tests.			10–20 per cent, 15 Tests.			20–30 per cent, 15 Tests.			30–40 per cent, 16 Tests.			Over 40 per cent, 28 tests.		
	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.
72 hours	245	160	192	260	143	190	190	125	152	135	90	125	170	44	83	110	40	61
7 days	384	233	301	420	222	340	343	225	270	262	110	222	288	100	200	265	90	170
28 days	502	300	410	605	380	438	431	296	365	403	187	344	462	178	311	376	133	271

WORK CONSISTENCY.

Period.	64 Tests.			10 Tests.			11 Tests.			11 Tests.			10 Tests.			22 Tests.		
	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.
72 hours	190	100	140	112	22	81	115	25	77	100	10	55	84	22	55	85	10	28
7 days	280	178	235	230	172	188	236	97	170	176	33	130	194	84	128	213	46	106
28 days	374	230	316	352	269	313	371	160	263	274	170	232	367	130	221	304	97	191

TABLE III.—SHOWING LOSS IN TENSILE STRENGTH AS SILICA CONTENT IS DECREASED.

NORMAL CONSISTENCY.

Period.	Ottawa Sand.			Natural Work Sands, with Silica Content of													
				Over 95 per cent.			90–95 per cent.			85–90 per cent.			80–85 per cent.			Less than 80 per cent.		
	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.
72 hours	245	160	192	200	165	187	185	90	160	168	80	136	165	40	80	56	44	41
7 days	384	233	301	414	280	330	379	160	272	290	97	232	317	90	211	276	130	213
28 days	502	300	410	568	435	487	605	256	398	462	165	360	414	195	326	415	190	298

WORK CONSISTENCY.

72 hours	190	100	140	108	64	89	100	36	64	115	45	57	84	10	43	36	15	21
7 days	280	178	235	229	103	187	236	83	160	192	101	147	220	47	133	210	33	132
28 days	374	230	316	371	203	304	370	148	275	316	222	262	326	173	237	312	143	235

that is, the consistency of a 1:3 Ottawa sand mortar when made according to the standard methods for testing cement. In the test just referred to the sand is made into a mortar of work consistency, that is, the consistency required in mortar to enable the concrete to be poured.

The practice of making comparative sand tests, using wet mixtures, was developed in our laboratory some years ago while we were trying to find the reason why a sand known to have caused trouble in a certain piece of concrete work, when mixed into mortar of normal consistency, gave tensile strengths greater than those obtained from the same cement and Ottawa sand.

The method of procedure in our laboratory is as follows: The sand to be tested and Ottawa sand are first made into mortars of normal consistency, using preferably cement from the work. These mortars are then made into briquettes, the whole operation being in accordance with the prescribed methods of this Society for the making of sand briquettes when testing cement. The amount of water necessary to make a mortar of normal consistency having been found, a new batch of sand and cement in the desired proportions is thoroughly mixed dry and placed in a cylinder that can be revolved, together with a number of flint pebbles, so that the proportion of the cement, sand and stone will approximate that desired in the actual work. To this mix is added enough water (generally about 50 per cent more than needed for normal consistency) to make a mortar having work consistency. The cylinder is then closed and revolved for five minutes. The flint pebbles are picked out by hand and the mortar is made into briquettes. This test more closely approximates the conditions found in actual work, and the strengths obtained from briquettes made from such a mortar, though, as a rule, far below those obtained from a mortar of normal consistency, correspond to those that may be reasonably expected from the mortar if the sand and same cement are used in construction.

It is to be noted that in most cases, using the same cement, more water will be needed to bring a natural sand to normal consistency than is necessary with Ottawa sand. This difference in the amount of water required is accounted for by the

difference in granulometric grading, the work sand, as a rule, having the greater amount of fine material, and hence more surface to be covered and a larger percentage of voids.

Further, it is to be noted that the strengths obtained from a natural sand when made into a mortar of normal consistency

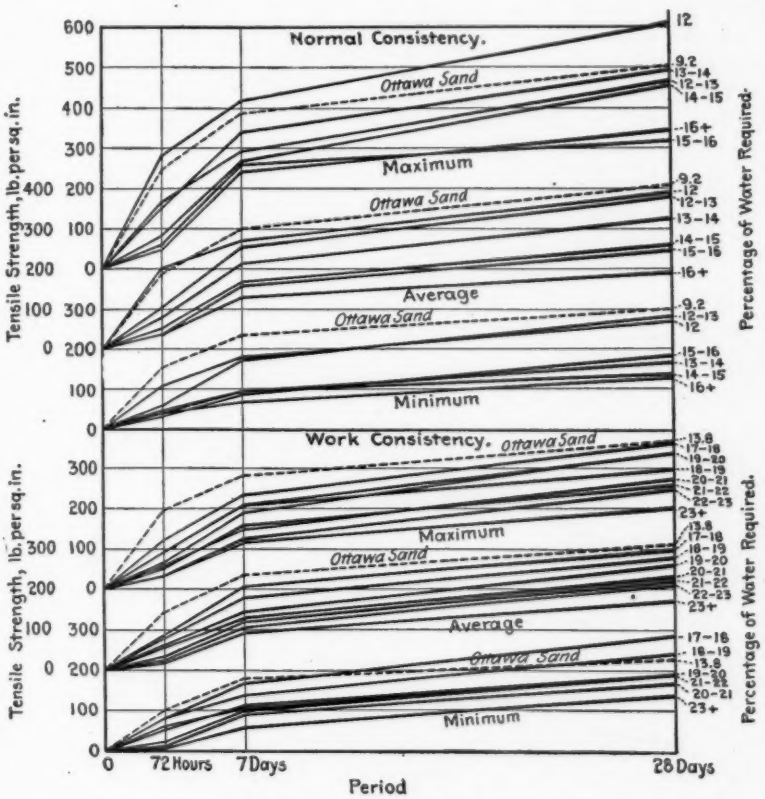


FIG. 1.—Graphical Development of Data in Table I.

are often equal to or greater than those obtained with the same cement, using Ottawa sand. When the same natural sand and cement are made into a mortar of work consistency, which requires about 1½ times as much water as for normal consistency, the reduction of strength will be more or less marked, depending on the character of the natural sand. The strength

of all sand mortars is affected by the amount of water used over that required for normal consistency. The more water used, the greater will be the loss in strength at early periods. The nearer a natural sand approaches the ideal in physical and chemical composition, the less will be the loss in strength for

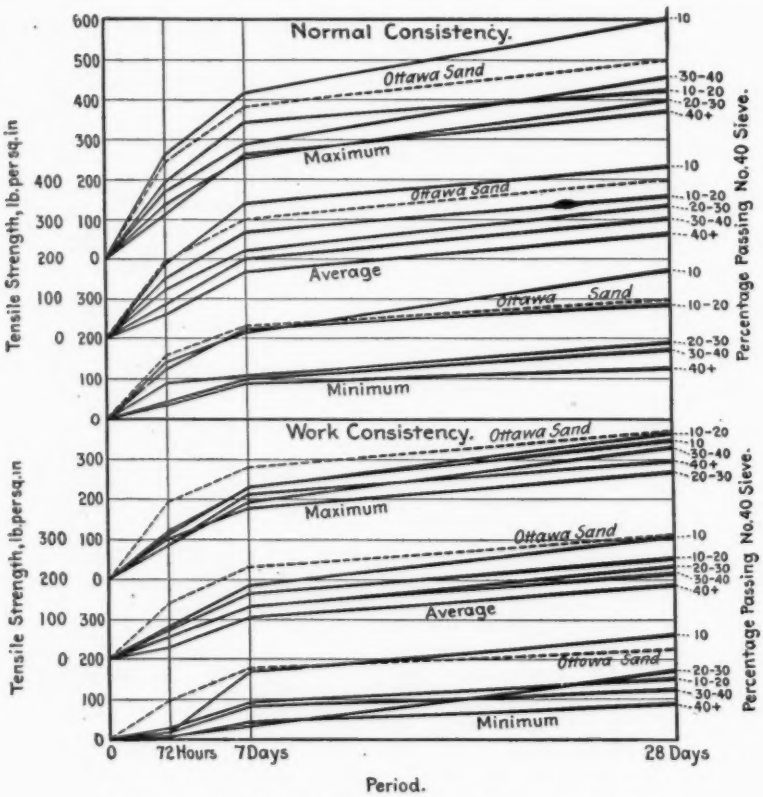


FIG. 2.—Graphical Development of Data in Table II.

each additional per cent of water added. The amount of water required to bring a given sand to work consistency forms one of the best measures of the quality of sand.

In mixtures using 50 per cent more water than required to produce normal consistency, Ottawa sand and good natural sands lose from 25 to 35 per cent of their strength up to

the 28-day period, while a poor sand may lose as much as 70 or 80 per cent of the strength developed when made into mortars of normal consistency. It has been found by experience that with two sands, other things being equal, the one having the smaller amount of fine material will have the less amount of surface to be covered, and when mixed with a

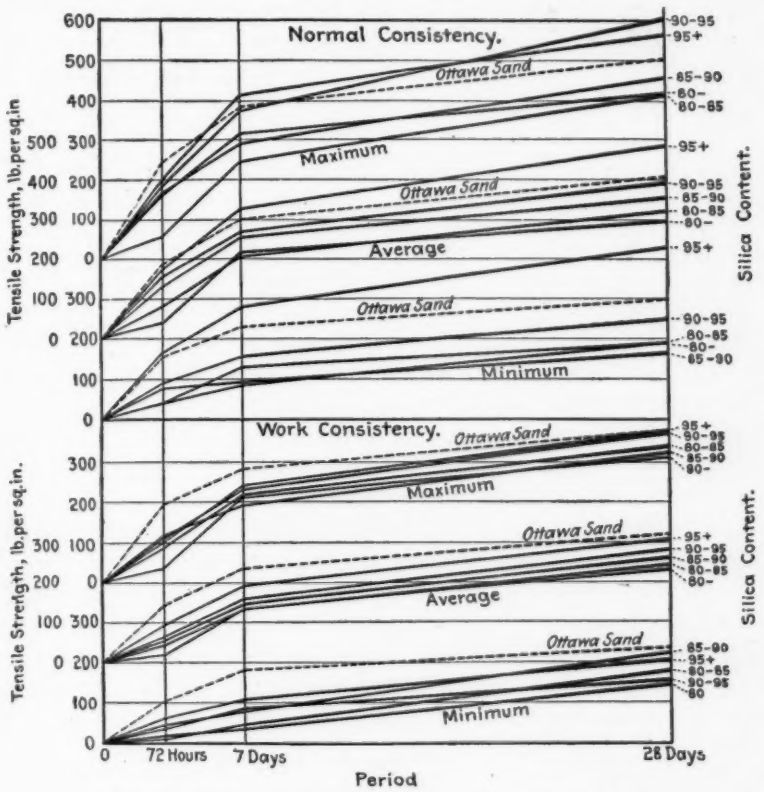


FIG. 3.—Graphical Development of Data in Table III.

given amount of cement will need less water to produce a definite consistency than the one containing a larger proportion of fine material.

Many engineers maintain that in making comparative tests of sand, the same amount of water should be used with each sand, overlooking the fact that in actual work one sand will

require more water than another to bring the mortar to the consistency required by the work. We cannot assume that the same percentage of water will give the same consistency with two different sands. If this practice is followed one sand may have too much water and the other too little. In the actual work where the sand is to be used, a concrete of a certain consistency will be made with no regard to how much water is needed to obtain it, and in order that the test may give a correct indication of the strength the sand will develop under actual work conditions, the test mortars should be made of a corresponding consistency. As stated before, most natural sands take about 1½ times as much water to produce work consistency as is required for normal consistency. This, however, is not true of Ottawa sand which, while taking less water to produce normal consistency, requires more than 50 per cent addition to produce a mortar of work consistency.

In general, it may be assumed:

1. That the less water required to produce a mortar of a given consistency, the higher will be the strength developed by the sand.
2. That the coarser the sand, other things being equal, the greater will be the strength developed.
3. That the higher the silica content, other things being equal, the greater will be the strength developed.
4. That where it is necessary to use sands of poor quality, loss in strength at early periods can be largely overcome by using a dry concrete.
5. That the loss of strength is confined chiefly to short periods, being practically overcome with time.

The graphical development of the results of the tests recorded in Tables I to III will help to make these points more clear (see Figs. 1 to 3). The tests were made during the past year, and cover sands received from various parts of the country, made up with various cements. It will be noted that while the average results conform to the general rules above given, the maximum and minimum show variations. This is due to the fact that other conditions may overcome, to some extent, the particular effect the results are intended to illustrate.

DISCUSSION.

Mr. Thompson.

MR. SANFORD E. THOMPSON.—The quality of sand may be considered in two general divisions: one with reference to the fineness or relative fineness of the particles and the other with reference to the impurities. The tests given in Mr. Reinke's paper take up both of these indirectly. The quality of fineness is the easiest to determine, as it is shown simply by a mechanical analysis test, from which one who is experienced in the testing of sands can draw certain general conclusions. If, however, the sand contains impurities, which frequently cannot be determined by the eye, any conclusions based on the sizes or relative sizes of the grains are overturned. Assuming, however, that the question of special impurities is left out of consideration, the first conclusion drawn by Mr. Reinke, that the smaller the quantity of water required to produce a mortar of given consistency the higher will be the strength developed by the sand, is a rational one. A fine sand, as is well known, takes much more water to produce a certain consistency of mortar when mixed with cement than does a coarse sand. A fine sand makes a weaker mortar than a coarse sand because of the lower density. These two conditions are directly related, because if a mortar is less dense it must have more voids, and in the first mixing of the mortar these voids are filled with water. Consequently, when the mortar does require an excess of water, it is evident that the mortar produced will be less dense, and consequently will have lower strength.

In order to make such a test of practical use, a more well-defined test for consistency must be formulated than any which we now have.

In Mr. Chapman's paper a method of test for consistency is suggested which is worth further investigation. A committee of which Mr. Chapman and the speaker are both members has used a similar test in determining the consistency of specimens of concrete used in a series of tests which the various college laboratories have been making under the auspices of this committee.

Mr. Thompson. I am not yet convinced that the introduction suggested by Mr. Reinke of the tension test for sand mortar, in which 50 per cent excess of water is used, is necessary in order to properly examine a sand. Undoubtedly an excess of water, especially with a sand containing a large proportion of fine particles, will give a lower ratio of strength compared with standard sand mortar of the same consistency than will tests with normal consistency. This, however, involves again the lack of a standard method of comparing the consistency of the standard sand mortar and of the mortar in question. Furthermore, the test using normal consistency alone I have always found to show up a sand which, on the one hand, is liable to give trouble in the work, or on the other hand, is incapable of ultimately producing a satisfactory strength in concrete.

The further conclusion that concrete of dry consistency should be used with a poor sand, while theoretically of interest, is difficult to apply in practice, because the consistency of a concrete usually has to be governed by the nature of the construction. A plastic concrete of a jelly-like consistency always produces stronger concrete than a wet mix and is to be preferred where conditions admit of its use. It is absolutely necessary, however, to employ in reinforced concrete a consistency sufficiently wet to flow around the steel and into the corners of the forms and, in rubble concrete, to flow around the large stones. There is, however, a tendency on the part of many builders to fail to appreciate the greater strength of a plastic mix, and to use a much wetter consistency than is required. A caution on this point is therefore timely.

Mr. Reinke. MR. W. B. REINKE.—Not long ago we had occasion to test sand which contained a whole lot of finely divided mica. It was tested normally and gave excellent results. Not long afterwards the structure itself started to fail and the cement was blamed. We made further investigations, and found that by making a slushy mixture of this sand and cement we got miserable results, which barely showed any strength at all. Since then we have been testing all sands with this excess gaging because poor sand will then be shown up; even Ottawa sand loses strength, and as Mr. Thompson has just said, a wet consistency is what we require in the field.

MR. THOMPSON.—I should like to ask Mr. Reinke whether, where it showed up well, he used the same percentage of water he did with the standard sand. **Mr. Thompson.**

MR. REINKE.—In reply I may say that we worked altogether for consistency; we used the same consistency as the normal consistency of Ottawa sand. **Mr. Reinke.**

MR. H. S. SPACKMAN.—I should like to say in connection with Mr. Thompson's last question that I conceived the same idea and thought that the varying of the amount of water with each sand so as to reach the same consistency with both sands was improper, and I had a series of tests made, using the same amount of water for the work sand as for the Ottawa sand; but I found this method was absolutely impracticable, the results being most erratic. In most cases we had entirely too little water for the work sand. We then increased the water used with the Ottawa sand, taking the average of the amount required for the two sands. This also gave very erratic results. We had too much water for the Ottawa sand and too little for the work sand. I think the practice of requiring a standard consistency, whether it be a normal consistency, as required by the standard methods for testing cement, or the consistency of the mortar as used in the work, the proper one. I believe that in order to obtain results of any value, the amount of water must be varied to meet the requirements of each sand. **Mr. Spackman.**

MR. GEORGE O. HAYS (*by letter*).—I should like to call attention to one or two general requirements for a good concrete sand not mentioned by Mr. Reinke in his very interesting paper, emphasize some of the points that he has endeavored to bring out, and take exception to others. **Mr. Hays.**

The hardness of the separate particles of aggregate is an important determination, increasing with the age of the concrete. As the cement becomes hard, there is a greater tendency for the stones themselves to shear through, thus bringing the degree of hardness into play. The grains should offer as high a resistance to crushing as the cement after attaining its best strength.

The ability of rock effectively to resist varied weather conditions, which concerns the texture and mineralogical composition of the material, is a very necessary quality when considering it for use in concrete. The presence of feldspar, mica,

Mr. Hays. hornblende, etc., in trap and granite does not appear to be especially detrimental to their weathering properties, but the opposite usually holds true when these minerals occur in gneisses, probably due to the different manner in which they are contained. The presence in aggregates of even small amounts of metal, such as copper, nickel and iron, as well as sulphur, frequently results in the disintegration of concrete.

The shape of rock particles determines to some degree the strength of the mortar or concrete. A flat-grained material packs less closely, and is generally inferior to material composed of particles of cubical fracture.

I wish to commend the statement that all comparative sand tests of cement-sand mortar should be based on compressive-strength values instead of tensile-strength values. The compression tests possess a great advantage in that they conform in most cases to the conditions of actual construction, since concrete is never designed to withstand tensile stresses. Furthermore, there is no constant relation between resistances to compression and tension. A study of the results of extensive tests conducted in the laboratory of the Universal Portland Cement Co., on a large number of widely different sands, shows that the ratio between compression and tension may vary within limits giving a range of several hundred per cent. On 22 different sands tested some years ago by the Structural Materials Division of the United States Geological Survey, at St. Louis, this ratio between compression and tension was found to vary practically between 3 and 24. Some one has figured out an empirical formula expressing the actual ratio found for each of these 22 sands, but it stands to reason that this formula would not hold for other sands. Attempts have been made to place this ratio at 6 or 8, but what is to prevent it from being any value from 3 to 24? In one case the assumption would be unsafe, in the other uneconomical. Undoubtedly compression tests furnish the real measure of the strength of mortars.

The statement is made that the less water required to produce a mortar of a given consistency, the higher will be the strength developed by the sand. The truth of this statement depends upon the primary causes, as the amount of water necessary to produce a given consistency for any sand depends

upon the quality and condition of the material. Assuming that the aggregate is free of non-siliceous material, the amount of water required to give the mortar a certain consistency, over that required by the cement itself, depends largely upon two things—the grading and surface condition of the separate particles. The grading determines the relative amounts of coarse, medium and fine grains, and thereby the amount of surface area to be taken into account and the percentage of voids. The surface area of particles and percentage of voids in the mass do not go hand in hand, but both depend upon the grading of particles, and both affect the amount of surplus water required to attain a certain consistency in mortar. The surface condition has to do with the cleanliness of the particles, which, in so far as the amount of water is concerned, reverts to the matter of absorption. In general, therefore, the less the amount of water required to produce a mortar of a given consistency, the higher will be the strength, other conditions being equal; but only too often in actual practice the other conditions are not equal, in which case an investigation of these conditions becomes of real importance. **Mr. Hays.**

I question both the advisability and truth of the statement that where it is necessary to use a sand of poor quality, loss of strength at early periods can largely be overcome by the use of a dry concrete.

The coarseness as well as the fineness of a good concrete sand is limited. The best sands will show not more than 40 per cent retained on the No. 10 sieve and not more than 5 per cent passing the No. 80 sieve. Both affect the grading.

There should be a standard set of specifications for the selection of concrete aggregates, especially sand; but such specifications would have to be very comprehensive and adaptable to different localities and different conditions, and probably can never be made with marked success until they are preceded by and based upon more thorough and extensive investigation than has yet been conducted.

MR. REINKE (*Author's closure by letter*).—In answer to Mr. Thompson, I desire to take the stand that our experience has shown that normal-consistency gaging of mortars does not show up the strength value of the material in actual use. We grant **Mr. Reinke.**

Mr. Reinke. that there is no standard method of determining consistency, either normal or wet, but with practice any given consistency of any number of sands can be determined by an experienced operator with a very small percentage of error.

Our experience, and probably the experience of others, demonstrates beyond question that a wet mix will not give the strength obtained from a normal one, no matter whether the sand is good or poor. It would seem to be plain that the abrasive action of the water and pebbles, used in the method described in this paper, wears down the poor material in a given sand, and that consequently the poorer the sand the greater the amount of wearing away or turning into mud of the particles of sand.

Mr. Hays' statement that hardness is necessary in sand is fully answered by the reference to silica content. His other point in regard to the shape of the grains, etc., is well taken. These discussions, however, cover chiefly natural sands where the particles may be assumed to be, for the most part, spherical. His other remarks seem to be chiefly elaborations of statements in the paper as a whole, and are altogether commendable and in agreement with general experience.

In regard to questioning the truth of the statement, that if a poor sand must be used, loss of strength at early periods can be largely overcome by the use of a dry concrete, it may be said that this statement is based on the point brought out that a given mortar, whether composed of a good or a poor sand and cement, will develop at earlier periods greater strength with a "normal-consistency" gaging than with a "wet-consistency" gaging.

The whole subject of sand testing is one of great importance, and, as Mr. Hays truly says, no standard set of specifications can possibly be formulated unless they are based on thorough and extensive investigation.

The paper was presented with a view of eliciting discussion and, if possible, to lead to the creation of a committee on specifications for concrete aggregates.

ACTION OF VARIOUS SUBSTANCES ON CEMENT MORTARS.

By Richard K. Meade.

The following experiments on the action of various substances on cement mortars were begun some five or six years ago, about the time that the agitation over the destruction of concrete by the alkaline waters of the West was first started, and were undertaken not only to see if such action was really likely to take place, but also to determine which of the salts ordinarily found in ground waters were the cause of such destruction.

The salts usually found in the so-called "alkali waters" of the West are also those which occur in sea water and are those present in largest amounts in many spring and river waters. They are sodium chloride, magnesium sulphate, calcium sulphate, sodium sulphate and sodium carbonate. In order to test the effect of solutions of these substances on cement mortars, a sample of normal Lehigh Valley cement was selected and from it a large number of sand briquettes were made.

Analysis and tests of the cement are given in Table I.

Table I.—Analysis and Tests of the Cement Employed.

Analysis.

Silica, per cent	20.20
Oxide of iron, per cent	2.50
Alumina, per cent	6.96
Lime, per cent	62.40
Magnesia, per cent	3.01
Sulphur trioxide, per cent	1.60
Loss on ingnition, per cent	2.38

Physical Tests.

Soundness.

Steam	O. K.	Cold water	O. K.
Boiling	O. K.	Air	O. K.

Fineness.

Passing No. 100	94.3 per cent
Passing No. 200	77.8 "

TABLE I—(*Continued*).

SETTING TIME.

Initial set	2 hr., 15 min.
Final set	6 hr., 30 min.

TENSILE STRENGTH, LB. PER SQ. IN.	Neat.	Sand.
1 day	315	...
7 days	765	245
28 days	875	340
3 months	885	415
6 months	885	435
1 year	890	510

All briquettes were made from a mixture of one part cement and three parts standard Ottawa sand. They were allowed to harden 28 days in air and then immersed in a solution of the salt. The briquettes were piled in such manner that the solution had access to almost their entire surface. Each figure given in the following tables is the average of tests on five briquettes.

The solutions in all cases except that of the calcium sulphate, which was a saturated solution, were made up of one part of the salt to 100 parts of water, to form practically a 1-per-cent solution. At first the solutions were changed every few days, but after the first month the solutions were changed weekly and after the first year less often. The results obtained are given in Table II.

TABLE II.—ACTION OF VARIOUS SALTS ON CEMENT MORTARS.

Age in Solution.	Tensile Strength, lb. per sq. in., after immersion in					
	Magnesium Sulphate.	Magnesium Chloride.	Calcium Sulphate.	Sodium Sulphate.	Sodium Chloride.	Sodium Carbonate.
0 days[1]	219	219	219	219	219	219
7 days	268	245	227	257	236	225
28 days	272	300	300	334	268	277
3 months	287	315	334	354	299	324
6 months	196	202	314	378	287	320
1 year	Disintegrated	115	209	271	310	337
2 years	...	Disintegrated	Disintegrated	141	325	360

[1] The briquettes were aged 28 days in air before immersion.

First it should be remembered that the 28-day strength of briquettes kept in air is much less than that of those kept in water. As will be seen from the results given in Table II, the sulphates have a marked action on concrete, which seems to be

most apparent in the case of the magnesium salt. The action of magnesium sulphate on cement mortars has been discussed quite voluminously of late and I will not go into it to any length in this paper beyond stating that we carefully analyzed the affected portion and the unaffected portion of a sand briquette which had been stored in a solution of magnesium sulphate. These analyses are given in Table III.

TABLE III.

	Before Immersion.	Unaffected Portion.	Affected Portion.
Silica, per cent	75.12	73.96	60.40
Oxide of iron, per cent	0.52	0.60	0.30
Alumina, per cent	1.15	1.30	0.64
Lime, per cent	14.80	14.50	14.21
Magnesia, per cent	0.70	1.66	3.64
Sulphur trioxide, per cent	0.33	0.83	5.78
Loss on ignition, per cent	7.02	7.14	14.97

The large increase in the magnesia and sulphur trioxide and the decrease in the oxides of iron and alumina indicate the elements which react with each other. The loss in silica may be due to chemical action also, but as the surface of the briquettes was very much attacked and the sand grains could be scraped away with the finger, I am inclined to think that the lower silica in the disintegrated portion was probably due to mechanical causes rather than chemical action. It will be noted that in almost all cases the first effect of the solution was to increase the strength of the briquettes and that signs of disintegration in no cases became evident until after a period of three months in the solution.

Some of the briquettes were even boiled in a 5-per-cent solution of magnesium sulphate for several days, and in all cases the briquettes were much stronger after boiling than they were before and fully as strong as briquettes boiled in pure water, showing how slow the action of the sulphates is.

The briquettes which failed were considerably swollen and presented much the appearance of a baked potato which had burst its jacket.

Various authorities have proposed at different times the use of divers ingredients in concrete exposed to sea water, with

a view to their reacting with the salts of the latter to form insoluble compounds which would protect the concrete. Most persistently suggested of these are the salts of barium, which form with soluble sulphates insoluble barium sulphate. I tried both barium chloride and barium carbonate. These were ground very finely and mixed with the cement. I employed 2 per cent of barium chloride with the cement, and also 2 per cent and 5 per cent of barium carbonate. Sand briquettes were made from these mixtures and the test pieces stored in a magnesium sulphate solution containing 10 grams of the salt to the liter. The results are given in Table IV, and, as will be seen, none of these compounds arrest the destruction.

TABLE IV.—ACTION OF MAGNESIUM SULPHATE ON CEMENT MORTARS CONTAINING BARIUM COMPOUNDS.

Age in 1-per-cent Solution of Magnesium Sulphate.	Tensile Strength, lb. per sq. in., of briquettes containing		
	2 per cent of Barium Chloride.	2 per cent of Barium Carbonate.	5 per cent of Barium Carbonate.
0 days[1]	181	115	166
7 days	...	221	257
28 days	213	246	346
3 months	306	311	346
6 months	265	204	274
1 year	146	Disintegrated	Disintegrated

[1] The briquettes were aged 14 days in air before immersion.

Some years ago an English chemist suggested the use of finely ground, burnt red brick as an admixture for concrete which was to be used in sea water. After reading this paper it occurred to me that the resistance to sea water claimed for high-iron cements might be due to the presence of oxide of iron in the cement. I therefore had sand briquettes made up containing oxide of iron in various forms and conditions, namely, red or ferric oxide, magnetic oxide of iron, venetian red (an impure oxide of iron made from low-grade iron ores, so-called "paint ores" of the Lehigh district), and finely ground red brick, using of these 5 per cent of the weight of the cement in each case and placing the briquettes in a 1-per-cent solution of the magnesium sulphate. The results are given in Table V. As will be seen the additions of iron compounds are in no way beneficial to cements to be employed in sea water.

TABLE V.—ACTION OF MAGNESIUM SULPHATE ON CEMENT MORTARS CONTAINING IRON OXIDES, ETC.

Age in 1-per-cent Solution of Magnesium Sulphate.	Tensile Strength, lb. per sq. in., of briquettes containing 5 per cent of			
	Ferric Oxide.	Magnetic Oxide.	Venetian Red.	Brick Dust.
0 days[1]	218	225	165	170
7 days	275	280	225	220
28 days	310	340	300	275
3 months	355	340	345	310
6 months	310	280	215	205
1 year	125	105	Disintegrated	Disintegrated

[1] The briquettes were aged 14 days in air before immersion.

I next tried waterproofing the mortar on the theory that if the circulation of water through the pores of the mortar could be stopped no chemical action could take place. I employed for this purpose both a high-calcium and a magnesian-hydrated lime, road oil (as recommended by Page), a mixture of silicate of soda solution and fish oil (a well known waterproofing compound), and lime soap (the basis of many waterproofing compounds). I also tried dipping the briquettes first in a hot solution of soap and then in one of alum (Sylvester's Process). The results of the tests of sand briquettes made from these mixtures and stored in magnesium sulphate solution (10 grams to the liter) are given in Table VI.

TABLE VI.—ACTION OF MAGNESIUM SULPHATE SOLUTION ON SO-CALLED WATERPROOFED MORTARS.

Age in 1-per-cent Solution of Magnesium Sulphate.	Tensile Strength, lb. per sq. in., of briquettes containing					
	15 per cent of Hydrated Lime (Calcium).	15 per cent of Hydrated Lime (Magnesian).	10 per cent of Road Oil.	2 per cent of Lime Soap.	2 per cent of Oil-Silicate Soda.	Treated with Alum and Soap.
0 days[1]	215	215	165	185	160	220
7 days	215	225	200	210	200	235
28 days	315	320	210	250	245	275
3 months	245	260	260	275	260	265
6 months	200	245	210	230	225	215
1 year	120	105	140	180	165	185

[1] The briquettes were aged 14 days in air before immersion.

It will be noted that, while the disintegration is evidently taking place in these test pieces, all of these compounds seem to

arrest it to some extent at any rate, and in the case of the lime soap and Sylvester Process this is quite marked.

I also investigated the action of magnesium-sulphate solution on cements high in silica. For this purpose, samples of commercial cement, one high in silica and low in alumina and one low in silica and high in alumina, were selected; sand briquettes were made of these and immersed in a solution of magnesium sulphate containing 20 grams to the liter, or practically a 2-per-cent solution. The cements selected had the following analyses:

	LOW-ALUMINA CEMENT.	HIGH-ALUMINA CEMENT.
Silica, per cent	23.24	19.86
Iron oxide, per cent	2.25	2.56
Alumina, per cent	5.03	7.60
Lime, per cent	63.55	63.12
Magnesia, per cent	3.05	3.10
Sulphur trioxide, per cent	1.51	1.66

As will be seen from Table VII, the low-alumina cement resists the action of magnesium sulphate much better than the high-alumina one.

TABLE VII.—ACTION OF MAGNESIUM SULPHATE SOLUTION ON HIGH AND LOW-ALUMINA CEMENTS.

Age in 2-per-cent Solution of Magnesium Sulphate.	Tensile Strength, lb. per sq. in., of	
	High-Alumina Cement.	Low-Alumina Cement.
0 days[1]	242	225
7 days	318	307
28 days	404	430
3 months	402	476
6 months	230	472
1 year	Disintegrated	500
2 years	...	425

[1] The briquettes were aged 14 days in air before immersion.

In the above experiments, both cements were commercial cements; but the high-alumina cement when received was not quite so finely ground as the other one, so it was ground to practically the same degree of fineness in a small jar mill (or to 86.2 per cent passing the No. 200 sieve), so that the fineness

of the two samples might in no way influence the results. Both these cements were made from cement rock and limestone.

In connection with the use of concrete for mine props, where it is often exposed to the action of dilute solutions of sulphuric acid, the following experiment was tried: Sand briquettes were allowed to harden 28 days and then were placed in a solution containing 250 grains of sulphuric acid (H_2SO_4) to the gallon. The solution was changed frequently and the briquettes broken at regular intervals. The disintegration of concrete by such acid water is shown by the following:

Age in solution....	0 days	7 days	28 days	3 mos.	6 mos.	1 year
Tensile strength, lb.	226	299	300	280	176	disintegrated

Several years ago the question of the action of oil on concrete was brought up at one of the meetings of this Society in connection with a paper by Professor Carpenter. In his experiments, oil was mixed with the concrete. In the discussion which followed the reading of the paper, a number of gentlemen suggested that what was needed most was information relative to the action of oil on concrete which had already hardened, in view of the employment of concrete for machinery bearings, engine room and factory floors, etc., where it is subjected after being fully hardened to the oil which leaks from the bearings of the machinery. I went home from this meeting and had a number of sand briquettes made and allowed them to harden 2 weeks in air. These were stored in air, in engine oil, in cylinder oil, and in black oil, and broken at stated periods. The results are given in Table VIII.

TABLE VIII.—ACTION OF LUBRICATING OILS ON CONCRETE.

Age in Oil.	Tensile Strength, lb. per sq. in., of briquettes kept in			
	Air.	Engine Oil.	Cylinder Oil.	Black Oil.
7 days[1]	248	252	235	234
28 days	233	240	273	222
3 months	287	251	221	181
6 months	303	232	209	131
1 year	293	231	203	Broke in clips

[1] The briquettes were aged 14 days in air before immersion.

It will be noted that the engine oil and the cylinder oil have practically no effect upon concrete. One would think that as the latter has a considerable proportion of animal oil in its composition it would be apt to appreciably affect concrete exposed to it. On the other hand, the action of the black oil seems strange in view of the fact that it is a straight mineral product. All of these briquettes had absorbed considerable oil, the actual gain in weight of each set at the end of the year being as follows:

In engine oil	10.6 per cent
In cylinder oil	0.0 "
In black oil	12.0 "

The briquettes in the black oil had not swollen perceptibly and seemed merely to be weak.

The experiments given above were all made upon very small test pieces and hence the action of the solutions upon them was much more rapid than it would be upon a large mass of concrete; and while in most of the above cases a year was sufficient to completely disintegrate the test pieces, in a large body of concrete such as a pier or wall, many years would be required to bring about this result. The experiments merely serve to show that even very dilute solutions of the salts of magnesium and the sulphates in general do have a destructive action on concrete and that the generally proposed remedies do not appreciably retard this. They indicate the desirability of employing low-alumina cements in sea-water construction. The experiments with the oils show that no destructive action is likely to take place where cement is used for floors in machine shops and engine rooms.

DISCUSSION.

Mr. A. S. Cushman.

Mr. Cushman.—I have conducted some investigations very similar to Mr. Meade's, and my findings have been almost the same as his, in so far as our work covered the same ground. I want to take this occasion to make a suggestion which I hope every one interested in this subject will follow up. I believe the Montana Experiment Station is correct in stating that the reason for the disruption of concrete under the action of alkali water is that sulphated waters, in filtrating into concrete, produce a chemical reaction that changes the calicum hydrates into calcium sulphates. Since the volume of calcium sulphate is greater than the volume of calcium hydroxide, a molecular force is produced which disrupts the concrete. It occurred to me that by adding some form of soluble commercial sulphate to the water before the concrete is mixed, it might be possible to take care of a sufficient quantity of the calcium hydroxide to prevent subsequent disruption. About five years ago I had a series of briquettes made up in which I used a number of soluble sulphates. The only briquettes that seemed interesting from the point of view of strength and appearance were those made with ferrous sulphate or ordinary commercial copperas. These briquettes when allowed to soak in alkali water for one year, instead of disrupting, developed a flinty hard consistency with very high tensile strength. Some of these briquettes broke at 1100 lb. per sq. in. The subject seems worthy of further study.

Mr. A. T. Goldbeck.

Mr. Goldbeck.—It may be interesting to note the results of Mr. Page's experiments on oil-concrete mixtures immersed in alkali water. Mortar briquettes mixed in the proportions of one part of cement and three parts of Ottawa sand, some with no oil, some with 5 per cent oil, and some with 10 per cent oil added to the mixture, were soaked in various solutions, including sodium chloride, sodium carbonate and sodium sulphate. The effect of the sodium chloride and sodium carbonate was practically nil; the sodium sulphate disintegrated the plain 1:3 mixture before the end of a year; the briquettes containing a 5-per-cent mixture of oil were disintegrated to some extent;

Mr. Goldbeck. whereas those containing a 10-per-cent mixture of oil were practically intact at the end of a year, showing that the oil had a beneficial effect in retarding the action of the alkali water on the mortar.

Mr. Walker. MR. P. H. WALKER.—Black oil is not a uniform material; it is known that certain mineral oils have naturally some organic acids or some acids at any rate, whatever they may be, aside from mineral acid, and it is also possible, I think, for an oil of this kind to contain sulphuric acid. I should like to know whether this oil was tested for acids.

Mr. Meade. MR. RICHARD K. MEADE.—I am sorry that I cannot give you very much information about black oil. I have talked with a couple of petroleum refiners about it since my results were obtained and they told me it was a residual oil. They stated that it contained no acid and should contain, of course, no animal fat, so I am entirely at a loss for an answer. It is a heavy oil that is used for lubricating very heavy machinery. I know from practical experience that the action is only on the surface of the foundation, but here it does seem to be a little soft. In some foundations a little hole is often made for the oil to run in, and if you will scratch around in this with a knife or lead pencil, you can usually scrape off some of the cement.

Mr. Thompson. MR. SANFORD E. THOMPSON.—To determine the comparative chemical action of sea water upon different cements, Mr. Feret in France has suggested a simple accelerated test.[1] The cements to be tested are each mixed with fine crushed marble in proportions 1 part of cement to 3 parts of marble, by weight, and into this mixture is introduced varying percentages of gypsum ranging from 5 to 20 per cent of the weight of the cement. The principle involved is that the gypsum will produce accelerated action so that in a very short period of immersion in fresh water the relative effect upon the specimens will be comparable with the effect upon the same cement made into ordinary cement mortar or concrete and immersed in sea water for a long period.

Not long ago, in connection with the construction of the sea walls for a large power station in Boston harbor, I made a

[1] "Effect of Sea Water upon Concrete," by R. Feret in "Concrete, Plain and Reinforced," Second Edition, p. 314.

series of tests along these lines. Some half dozen representative brands of cement were selected, and briquettes were made up, as described above, using 20 per cent of gypsum, and immersed, after hardening, in fresh water. At the end of two months the difference between the brands was in many cases very distinctly marked. Chemical analysis of the cements showed that those with the smallest percentage of alumina stood the test much better than the cements containing higher alumina. The **Mr. Thompson.**

TABLE I.—EFFECT OF SEA WATER UPON MORTARS OF DIFFERENT PROPORTIONS MADE WITH THE SAME CEMENT AND STANDARD SAND.

Proportions.	Immersion.	Tensile Strength, lb. per sq. in., at			
		28 days.	3 months.	4 months.	5 months.
1 : 3	Plain water	292	400	...	...
1 : 3	Sea water	340	378	370	...
1 : 3	Sodium sulphate	310	0	0	...
1 : 2½	Plain water	381	465	...	...
1 : 2½	Sea water	409	446	503	331
1 : 2½	Sodium sulphate	359	117	0	0
1 : 2	Plain water	485	545	...	...
1 : 2	Sea water	480	553	530	505
1 : 2	Sodium sulphate	457	408	346	
1 : 1½	Plain water	532	565	...	...
1 : 1½	Sea water	581	618	625	555
1 : 1½	Sodium sulphate	591	547	545	503

briquettes made with cement containing less than 7 per cent alumina were hard and sound, while the briquettes with cement having more than 7 per cent alumina were soft and swollen. As a result of the tests, a brand of cement low in alumina was selected for the job.

The effect of sea water upon standard sand briquettes of different proportions is shown in the tests recorded in Table I. The sea water was concentrated by evaporation to double

Mr. Thompson. strength, while the sodium sulphate solution was practically saturated. Although the tests were not carried to a long enough period to produce disintegration in the richer mixtures, the results indicate the relative effect of rich proportions and also afford some comparison of the action of concentrated sea water and sodium sulphate solution. The cement is one of the standard brands made in the Lehigh Valley.

Mr. Bates. MR. P. H. BATES.—The Bureau of Standards has recently published a paper on the effect of alkali and salts present in sea water on concrete. The paper covers the whole field that has been discussed here, and gives more results than have been brought forward at any one time. I do not think, however, that any mention is made of the action of ferrous sulphate. This was tried, however, but it disintegrated the mortars used so rapidly that little work was done with it. I might mention that the first disintegration of concrete that ever came to my attention was the partial destruction of the concrete lining of a railroad tunnel which pierced a coal vein. The water percolating through this coal, before coming in contact with the concrete, took up large amounts of acid ferrous sulphate into solution, and this caused the disintegration of the concrete.

Though the Bureau of Standards did present a great number of results in this paper, it cannot be said that it showed conclusively what took place when this disintegration occurred. As Mr. Meade has shown, various salts either produced or did not produce a reduction in strength, but what caused this action has not been shown, and I cannot conceive how this latter can be accomplished until we know what takes place in cement when it hydrates in the presence of pure water. Knowing this, we can readily determine what will take place when various salts are present in the water.

Mr. Spackman. MR. H. S. SPACKMAN.—I should like to say very briefly in this connection that the action of the salt added to the cement in the gaging water before setting is very different from the action of the solution of the same salts penetrating the mortar after the setting. If the salts are added during the plastic period, and the formation of new compounds is accompanied by expansion, the cement adjusts itself to them. If the solution is absorbed after the cement has set and hardened, the mass is

too rigid to allow of expansion without strain. I think this accounts for the different action of salts absorbed by the concrete after it has set, and those during the period of setting. Mr. Spackman.

MR. BATES.—Mr. Richard L. Humphrey was one of the first to examine the concrete in connection with the Reclamation Projects of the United States Government in the West. He collected a large number of samples; later, I went out, and since then Mr. Wig, of the Bureau of Standards, has gone over a number of the projects. I collected alkali analyzing 90 per cent sodium sulphate on concrete. The disintegration takes place between the high and low water. Where the water seeps up through the ground around the concrete, the ground will be white with the alkali during some seasons. In such cases saturated solutions of the alkali are acting on the concrete. We find generally the same results as those obtained by Mr. Meade: the sulphates of soda are very active but the sulphates of magnesia are more so than the sulphates of soda. The presence of chloride of magnesia accelerates the disintegration. Mr. Bates.

MR. R. J. WIG.—Although we have no satisfactory explanation of the reactions that take place in the hardening of cement, we must continue to build structures exposed to the action of sea and alkali waters. We have to have assurances as to their permanency, which makes it necessary that we should carry on physical tests simply to develop the permanency of the material, for it may be years before we can actually determine the reactions which are taking place. The Bureau of Standards has made a survey of practically all the important concrete structures on the Atlantic seaboard, along the eastern portion of the Gulf Coast and at Panama, which are exposed to sea-water action, and there is not one case in which we can say that the destruction is due entirely to decomposition by the salts in sea water. There are cases of failures but their cause is entirely open to question. Where the surface was badly pitted or broken away, either through faulty workmanship or abrasion due to floating articles in the water, the exposed cement in some cases had softened somewhat. We have an instance of some concrete cubes, a cubic meter in size, which were made up by the French at Panama prior to the assumption of the Canal by the United States, in which decomposition of the aggregate is shown. Local Mr. Wig.

Mr. Wig. soft shales were used and they have badly decomposed showing marked pitting of the concrete, while the cement mortar is perfectly sound in most cases. Other cubes of approximately the same size were placed in sea water by the Americans in 1908 and 1909, and in practically every case the edges of these cubes are perfectly intact, there being no indication whatever of disintegration.

Referring to Mr. Cushman's remarks regarding the action of the sulphates, I should like to mention some results which we obtained. We made several thousand cement briquettes, increasing the sulphates in the cement by the addition of plaster of Paris. We found some of our strength values running up as high or even higher than those obtained by Mr. Cushman. The briquettes were also very brittle and hard, as he suggests, but I should like to point out one thing: that extreme care should be used in generalizing at all from any briquette tests, for very slight variations in the setting property of the cement will cause extreme variation in the results. If cement is exposed to alkali salts or sea water after it is a few hours old, say 24, it may disintegrate inside of 4 to 26 weeks; while if allowed to set for even two days before exposure, it may show no disintegration after a period of a year or more.

While in the Southwest, we observed in New Mexico a number of cases where the concrete was badly disintegrated by the sulphur waters and they are looking for some means of protection. The sulphur content of the water is very high; I cannot say just what the percentage is, although we have analyses of it. A program of field tests has been outlined by the Bureau of Standards to determine the resistance of concrete in the form of drainage tile to the alkali found in the various states of the West. We are placing, in cooperation with the Agricultural Department and the Reclamation Service, running drains in some typical western states, including Utah, New Mexico, Montana, Wyoming, Arizona, Colorado and Washington. These drains will be continued for a period of years and accompanying tests will be made to determine the actual service value of tile of various mixtures.

Mr. Spackman. MR. SPACKMAN.—I should like to ask whether the Bureau of Standards has made any investigation to determine whether

there is a possibility of disintegration being developed through the mere crystallization of salts in solutions without any direct chemical attack on the cement medium itself, in the same manner as in the freezing test for stone, where the stone is immersed repeatedly in a solution of salts and dried, the crystallization on drying representing the expansive force of water on freezing. Has any such result been noted in this alkaline water? Mr. Spackman

MR. WIG.—The possibility of the disintegration of stone by crystallization of salts is just as great as in the case of concrete, and undoubtedly in some cases, as shown in Technologic Paper No. 12 published by the Bureau of Standards, the disintegration is totally, or in large part, due to the rupture of the concrete from the expansion and mechanical action resulting from the crystallization of the salts Mr. Wig.

TESTS OF NATURAL CONCRETE AGGREGATES.

By R. S. Greenman.

In June, 1911, there was presented before this Society by the writer a paper on "Practical Tests of Sand and Gravel Proposed for Use in Concete."[1] The object of that paper was to show the aid of certain laboratory and field tests in the selection of proper sands and gravels for general or special uses in concrete. The writer still stands by the deductions then made; but he wishes to show, under the head of "Tests of Natural Concrete Aggregates," that these tests do indicate the relative values of fine or coarse aggregates in actual concrete, and also to add a few suggestions that might help the engineer or contractor in the choice of his aggregates.

It is generally conceded that the relation of voids, loam and sizes of grains do have a bearing on the quality of the aggregates —the final essential quality of which is the ability to give strength. This strength of the materials has very generally been gaged by tensile tests, but it must be admitted that while these tests have given comparable results, they have not given actual results but results merely indicative of what the material may do. It must be admitted, too, that it is almost impossible to get tests of the actual concrete. Various methods of securing satisfactory test pieces and unique ways of testing concrete in place have been suggested but these have not, as a rule, been generally well received. The best plan to date seems to be to take samples of the concrete while being placed and mold them with as little work and as quickly as possible into small test pieces. These can be kept as near as possible in the same actual atmospheric conditions as the concrete from which the samples were taken. At regular periods these test pieces can be tested for compressive strength.

That concrete test pieces so made give very little satisfaction in determining the qualities of concrete aggregates is quite a general opinion. Out of a large number of tests of con-

[1] *Proceedings*, Am. Soc. Test Mats. Vol. XI, p. 515 (1911).

crete cubes made in general as stated, the writer has endeavored to find out whether such is the actual case. Results of comparable tests were selected from series having similar characteristics; and after the results of the compression tests had been tabulated, the original laboratory tests of the aggregate were added to the tabulation. This statement is given so that an impression may not be had that the examples selected were specially chosen, but rather that they do indicate that the tests are correlative and corroborative.

In considering results of tests little reliance should be placed on a single test piece. In Table I there are given results

TABLE I.

Series No.	Proportions, Cement: Gravel.	Concrete Tests.		Sand Tests.				
		Number of Cubes.	Compressive Strength at 28 days, lb. per sq. in.	Percentage of			Tensile Strength at 28 days, lb. per sq. in.	
				Run of Bank.	Voids.	Loam.	Bank Sand.	Standard Sand.
1.....	1 : 5.6	2	3465	40.7	26.7	4.6	343	272
		1	2611					
		Av.	3177					
2.....	1 : 0	1	3113					
		1	2631	36.2	28.4	3.5	394	342
		Av.	2872					
3.....	1 : 5.7	1	3109					
		1	2606	..	....	...	...	...
		Av.	2857					

of tests where the same brand of cement and the same gravel were used on each of three contracts by different contractors. Attention is called to the remarkable similarity of the average results secured and also to the fact that in each set of cubes the "low" block contained a "porous" bottom and gave practically the same results. There was a rather wide range between high and low "breaks"—explained by the porous bottom—and this well illustrates the folly of basing conclusions on one test piece only. The gravel being used was the "run of the bank" and necessitated frequent field tests for characteristics to determine the proportions to be used. As a rule these proportions were 1 part cement to 5.6 parts gravel to replace the 2.5 parts sand and 5 parts gravel required by the contracts.

In Table II another comparison will indicate results corroborating laboratory tests for relative values of sands. A different brand of cement from that in Table I was used, but the same brand was used for the three different series. Crushed stone from one quarry was also used for the coarse aggregate on all three contracts. The sands were from different banks, although series Nos. 4 and 6 were similar sands taken from adjoining banks; No. 5 was taken from a bank which has a characteristic quality peculiarly its own.

Since the variable material here must be in the sand a study of the results readily shows that the tests do give corroborative results and that they should aid in the making a choice of the sand to be used. An explanation should be given to the

TABLE II.

Series No.	Proportions, Cement: Sand: Stone.	Concrete Tests.		Sand Tests.			
		Number of Cubes.	Average Compressive Strength, lb. per sq. in.	Percentage of		Tensile Strength at 28 days, lb. per sq. in.	
				Voids.	Loam.	Natural Sand.	Standard Sand.
4.....	1 : 2.0 : 4	3	2577	....	...	...	...
5.....	1 : 2.5 : 5	3	1755	35.3	1.2	201	322
6.....	1 : 2.5 : 5	3	2651	26.9	4.2	308	295

fact that here a richer concrete gave a lower result than did a leaner one. The richer concrete was for reinforced concrete and the test pieces plainly indicated that the concrete when placed was a rather wet concrete and would, of course, produce in the relatively early test a lower strength. The point is thus emphasized that it would be folly to accept any result of the test without noticing every characteristic of the test piece. In other words, judgment as to the value of the material must be based upon careful tests, study and common-sense perception.

As a further illustration of the need of perception in drawing conclusions, the results of compressive tests made on four cubes of concrete received from one contract are given in Table III. All were made at the same time and from the same

materials in the proportions of 1 part cement, 2 parts sand and 4 parts local gravel, washed and screened.

It will be noticed that there is a fairly close "break" in the four blocks, but why not still better? An examination of the crushed blocks clearly showed that Nos. 2 and 3 contained a

TABLE III.

Series No.	Cube No.	Compressive Strength at 28 days, lb. per sq. in.	Cube No.	Compressive Strength at 28 days, lb. per sq. in.
7.....	1	2263	2	1944
	4	2288	3	1989
	Average	2276	Average	1967

larger number of soft sandstone pebbles. It had been noticed in the examination of the gravel before its use that one of the objectionable features was the presence of soft sandstone pebbles. The test not only confirmed the judgment that they were a point of weakness in the gravel, but directly pointed out the fact and did not leave it a matter of personal opinion.

And again along the same line of argument. A study of

TABLE IV(*a*).

Series No.	Proportions, Cement: Sand: Gravel.	Concrete Tests	
		Number of Cubes.	Average Compressive Strength at 28 days, lb. per sq. in.
8.....	1 : 2 : 4	3	1514
9.....	1 : 2.5 : 5	3	1593
10.....	1 : 3.5 : 7	3	1234

TABLE IV(*b*).

11.....	1 : 2 : 4 (Gravel)[1]	3	2326
12.....	1 : 2 : 4 (Stone)	3	2473

[1] Washed and screened.

Table IV(*a*) will show that specifications calling for definite proportions of materials do not necessarily provide for the best concrete by simply asking for richer proportions. In other words, a 1 : 2 : 4 mixture may not produce as good concrete as a 1 : 2.5 : 5 mixture. Cubes apparently mixed with equal care

and from the same materials, but in different proportions, were submitted for tests.

The richest mixture here gave slightly lower results than the next leaner. Reasoning as before, it might be said that it was because the consistency was different. This may be true; but an examination of the test piece showed no great difference in this particular. A comparison of the proportions and resulting strengths will show, however, that the leanest mixture gave in proportion of aggregates to cement the relatively best result. Then would it not be fair to assume that the characteristics of the sand and gravel as to voids, grading, etc., had a decided effect upon the results of the tests, and that there is a relative proportioning that will give to the concrete the greatest strength the cement might be capable of producing?

TABLE V.

Series No.	Sand Bank.	Coarse Aggregate.	Concrete Tests.		Sand Tests.				
			Number of Cubes.	Compressive Strength at 28 days, lb. per sq. in.	Percentage of			Tensile Strength at 28 days, lb. per sq. in.	
					Run of Bank.	Voids.	Loam.	Bank Sand.	Standard Sand.
13...	A	Gravel and sand	3	2066	50.9	27.5	2.3	284	278
14...	B	Gravel and sand	3	2298	55.2	31.5	7.9	280[1]	314
15...	B	Screened gravel	3	1954	55.2	31.5	7.9	280[1]	314
16...	C	Gravel and stone	6	1450	75.3	32.5	0.5	188	281

[1] Washed sand.

Examination of Table IV(*b*) will show that a little extra attention given to a material may result in a far better product. In series No. 11 the gravel was washed and screened with a very decided improvement in the material. The relative value of the gravel and crushed limestone is slightly in favor of the stone, in so far as the compressive strength is concerned.

In another work the relative value of different sands and gravels and crushed stone was determined from a long series of tests. Some typical results were selected and are given in Table V.

A further study of these results will show that the claims made previously in this paper are true, that there is a distinct relation between the effect of the aggregates in actual concrete

and the tests made in the laboratory. In these series the same cement was used in all tests. The gravel in the bank run was deducted from the stone used; the proportions used were 1 part cement, 2.5 parts sand and 5 parts combined stone and gravel, except in series No. 15 where only screened gravel was used. Series Nos. 14 and 15 were made with a sand slightly inferior to No. 13 but had less of the gravel element. Series No. 16 had the larger stone element but was made of a relatively much poorer sand.

In considering the relative value of the aggregates under inspection one cannot overlook the fact that concrete made from different cements will produce different strengths with any one aggregate; but it must be remembered that in considering the results of the tests, due allowance must be made for the relative early strengthening qualities of the cement being used. Hence, to expect or to specify that all concrete shall give a crushing strength of any given number of pounds would not mean that the aggregates would be especially good, but rather that the cement might have a high initial strength which may or may not be beneficial, depending on the view point. So in drawing conclusions from results of tests of concrete, one must keep in mind the "strength characteristics" of the cement used.

It had been the original intention of the writer to discuss minutely the methods of making field tests of natural concrete aggregates and to show the bearing each test has on the selection of the best aggregate. But feeling that it might be considered discourteous to fellow members of a committee which is making a study of methods, it was decided to treat the subject with the main object of trying to show to the skeptical mind that both the laboratory tests and carefully made field tests and inspections do present ways and means of indicating what the natural aggregate, either fine or coarse, will actually do in the concrete in place. That is, with the same methods of making concrete and under the same or similar conditions the relative value of the materials is clearly indicated. It must, of course, be thoroughly understood that a separate test without a consideration of all the phases and conditions, cannot be an infallible guide; but each test made is one more aid to the selection of the aggregate best suited for the purpose intended.

TESTS OF MORTARS MADE FROM WISCONSIN AGGREGATES.

By M. O. Withey.

About three years ago the Mechanics Department of the University of Wisconsin began an extensive schedule of tests on mortars and concretes made from Wisconsin aggregates. The purpose of the experiments is to determine both the suitability of these aggregates and the properties of the concretes or mortars made from them. From time to time when tests on a sufficient number of aggregates have been completed the results will be published in University bulletins. The latter are available without charge to residents of the state and may be obtained at a nominal fee by others.

The adopted program of experiments is, to a considerable extent, modeled upon that formerly employed at the United States Geological Survey Laboratory at St. Louis.[1] Inasmuch as a résumé of the program and methods of testing has been published,[2] only a brief statement of the latter will be given herein. In this paper will be made a preliminary report of tests on fifteen small aggregates and sixty mortars made of them.

In presenting this report due acknowledgment is made for the careful assistance rendered by Messrs. Andrew Ludberg, E. B. Nelson, C. M. Osterheld, E. J. Paulus, and H. E. Pulver in making and testing specimens. Mr. S. D. Wonders has carefully prepared and checked the tables and diagrams for this paper. The courtesy of the pit and quarry owners who furnished the material for the tests is also much appreciated.

Aggregates.

A list of the aggregates and the results of physical tests upon them will be found in Tables I and II. Concerning the characteristics of the aggregates themselves the following brief

[1] *Bulletin No. 320*, United States Geological Survey.
[2] *The Wisconsin Engineer*, Vol. XVI, p. 99; also *Concrete*, Jan., 1912, p. 55.

statement is appended. Sd. 1, Sd. 2, Sd. 5, Sd. 7, Sd. 10, and Sd. 11 were untreated bank sands; Sd. 4 was obtained from a large pit of nearly pure silica sand; Sd. 3 and Sd. 8 were pit sands which had been washed; Sd. 9 was obtained from the shore of Lake Michigan; Sg. 1 was a hard quartzite screenings; Sg. 3

TABLE I.—PROPERTIES OF SANDS AND SCREENINGS.

Material No.	Weight per Cu. Ft., lb.	Specific Gravity.	Voids, per cent.	Silt, per cent.	Absorption, per cent.	Locality.	Secured from
S[1]	104.1	2.65	37.0[a]	....	....	Ottawa, Ill..	Ottawa Silica Co.
Sd. 1	105.2	2.66	36.5	3.0	0.19	Janesville...	Janesville Sand & Gravel Co.
Sd. 2[2]	106.9	2.74	35.2	1.3	0.49	Madison....	John Pieh.
Sd. 3	101.8	2.68	38.2	0.8	0.27	Onalaska...	Onalaska Pickle & Canning Co.
Sd. 4	98.9	2.63	39.8[a]	1.2	0.04	Portage.....	Columbia Silica Co.
Sd. 5	91.2	2.67	45.3[a]	0.5	0.17	La Crosse...	La Crosse Stone Co.
Sd. 7	105.2	2.78	36.6	1.6	0.41	Milwaukee..	J. C. James.
Sd. 8	105.3	2.70	36.4	1.5	0.18	Beloit.....	Atwood-Davis Sand Co.
Sd. 9	105.5	2.75	36.0	0.7	0.51	Racine.....	A. & S. Hansche.
Sd. 10	120.3	2.77	27.9	7.7	0.29	Waukesha..	Waukesha Lime & Stone Co.
Sd. 11	108.7	2.72	35.0	0.4	0.11	Palmyra....	A J. Thorne.
Sg. 1	92.8	2.67	42.0	14.7	0.05	Baraboo....	H. E. French.
Sg. 3	95.2	2.82	39.0	16.2	0.19	Milwaukee..	Story Bros.
Sg. 4	94.9	2.75	40.0	9.3	0.47	Racine.....	Universal Crushed Stone Co.
Tg. 1	96.8	2.81	43.6	4.0	0.10	Platteville...	Hodge Mine.

[a] Computed: $\frac{\text{Sp. Gr.} \times 62.4 - \text{Wt. per Cu. Ft.}}{\text{Sp. Gr.} \times 0.624}$ = Percentage of Voids.

[1] Standard Sand.

[2] Torpedo grade.

and Sg. 4 were hard magnesian limestone screenings; Tg. 1 was dolomite tailings from a lead and zinc mine. In the bulletin which is being prepared more complete information regarding these aggregates will be afforded by chemical analyses and by photographs. The sizes of the samples of materials consigned to the laboratory varied from 5 cu. ft. to 1½ cu. yd.

PHYSICAL TESTS OF SANDS AND SCREENINGS.

The methods employed to obtain the results recorded in Table I will now be briefly explained. Weight per cubic foot was determined by allowing sun-dried material to fall freely from a height of 3 ft. into a 1-cu-ft. measure, striking off the top of the measure with a straight edge and weighing. The rate of flow into the measure was 1 cu. ft. per minute.

TABLE II.—RESULTS OF MECHANICAL ANALYSES ON SANDS AND SCREENINGS.
(All materials were passed through ¼-in. sieve before using.)

Material No.	Percentage by Weight Passing Sieves Nos.—							Uniformity Coefficient.
	10	20	30	40	50	74	100	
S	100.0	100.0	0.0	....	....	....	....	....
Sd. 1	86.4	65.5	39.0	25.0	9.1	5.4	2.8	3.0
Sd. 2	81.2	70.9	61.4	52.4	34.5	17.9	9.7	2.6
Sd. 3	91.9	72.7	39.7	26.4	13.7	4.2	1.2	2.4
Sd. 4	100.0	99.5	95.8	88.8	62.5	22.1	8.6	1.8
Sd. 5	100.0	99.9	99.8	99.1	67.6	18.2	5.7	1.8
Sd. 7	67.7	44.5	25.9	17.8	11.2	3.8	2.2	4.7
Sd. 8	82.0	72.5	55.3	38.6	16.1	3.6	1.9	2.6
Sd. 9	66.8	22.7	13.9	10.3	4.9	2.4	1.4	3.7
Sd. 10	69.7	48.8	34.0	26.3	17.4	8.7	6.5	6.9
Sd. 11	72.0	47.7	23.8	12.0	4.3	0.7	0.5	3.4
Sg. 1	62.8	43.8	35.5	31.5	25.1	17.4	13.0	13.2
Sg. 3	64.0	38.8	28.0	23.8	19.5	15.8	13.8	16.3
Sg. 4	69.0	44.0	32.6	28.3	23.8	18.5	15.9	18.8
Tg. 1	34.6	19.8	15.4	13.7	11.5	8.8	7.5	18.9

In determining the specific gravity, 0.3 lb. of dried material was carefully weighed on scales sensitive to 0.0001 lb. and placed in an Erlenmeyer flask connected to the exhaust of an air pump. When a vacuum of 27 in. had been attained the flask was filled with water and weighed under water. In addition the weight of the submerged flask alone was determined. The dry weight divided by the difference between the dry weight and the weight of the submerged material gave the specific gravity.

Percentage of absorption was determined upon the material used in the specific gravity test as follows: The aggregate was spread upon a glass plate and currents of air blown upon it until the surface felt dry and the material no longer stuck together. The weight was then determined. After drying, the material was again weighed. The ratio of the loss in weight to the dry weight multiplied by 100 gave the results in column 6 of the table.

In determining the percentage of voids an apparatus consisting of an 8-in. pipe capped at the lower end and provided with a water gage and scale reading to 0.001 cu. ft. has been found convenient. The volume of water displaced by $\frac{3}{4}$ cu. ft. of aggregate was determined by slowly pouring the aggregate into the voidmeter partly filled with water and noting the difference between initial and final readings of the water gage. The percentage of voids was gotten by dividing the difference between the loose volume of the material and the displaced volume of water by the loose volume and multiplying by 100. Corrections were made for the moisture content in the material and the absorption while in the voidmeter, in order to eliminate the air voids within the particles. The results obtained by this method are higher than those computed from the specific gravities. This is especially true for fine materials like screenings in which there is a large amount of dust. However, since voids are often determined in this way these results may be of interest.

The silt test was made as follows: A 100-g. sample of dried aggregate was carefully weighed and placed in a percolator suspended in a vertical position. The percolator was provided with an inlet at the lower end, which was covered with a fine screen, and an outlet on the side 12 in. above the bottom. Clean water was admitted from an aspirator bottle placed 3 ft. above the outlet on the percolator and the silt washed out of the material into a milk can. At one-minute intervals the material in the percolator was vigorously stirred for ten seconds. The process was discontinued when the water cleared immediately after stirring. A portion of the effluent caught in the milk can was filtered, dried, and preserved for chemical analyses. The amount of silt was determined by finding the difference between the weight of the dried residue in the percolator and the weight of

the original sample. The average of two determinations is reported.

Table II contains the results of sieve analyses. The ¼-in. sieve was used in separating fine aggregate. All material passing this sieve was classed as sand or screenings. In making the test a representative 2000-g. sample selected by the method of quartering was poured into a nest of sieves operated by a mechanical shaker, and shaken for ten minutes. Curves of the various aggregates were plotted with percentage passing a given diameter of mesh for ordinates and diameter of mesh for abscissas. The uniformity coefficient was gotten by dividing the diameter corresponding to a point on the curve having an ordinate of 60 per cent by the diameter of a point having an ordinate of 10 per cent. This quantity is considered by some to furnish a valuable index of the gradation of the particles composing a sand.

TESTS OF CEMENTS.

In order to secure a Portland cement which would vary in quality as little as possible, equal portions of five standard brands—Alpha, Atlas, Chicago A A, Medusa and Universal—were mixed. The constituent brands were purchased in open market. Each mixture consisted of approximately seven barrels and was given a distinguishing letter and number. Both the constituent brands and the mixtures were subjected to the standard tests prescribed by the American Society of Civil

TABLE III.—PROPERTIES OF MIXTURES OF FIVE PORTLAND CEMENTS.
(Cements composing mixtures: Alpha, Atlas, Chicago AA, Medusa, Universal.)

Cement No.	Normal Consistency.	Time of Set.		Soundness.	Fineness, Percentage of Residue on Sieve No.—		Specific Gravity.[1]
		Initial.	Final.		100	200	
M 11.....	20.5	2 hr. 3 min.	5 hr. 57 min.	O. K.	5.6	21.7	3.10
M 12.....	22	2 " 5 "	3 " 20 "	O. K.	4.0	23.3	3.10
M 13.....	22	2 " 5 "	4 " 5 "	O. K.	4.1	23.4	3.10

[1] Dried but not ignited.

Engineers, and in addition both tensile and compressive strength tests were made at 60, 180 and 360 days. The compression tests of cements were made on 2-in. cubes. Results of the tests on the mixed brands used in the experiments reported will be found in Table III and in Fig. 1.

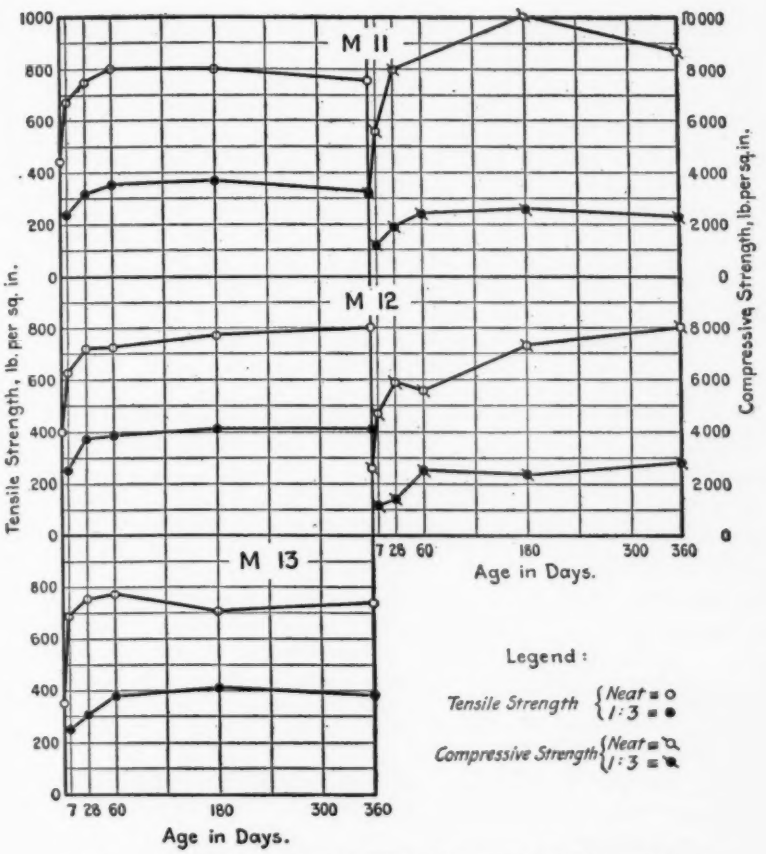


FIG. 1.—Strength of Mixed Brands of Cement at Different Ages.

The three mixtures were made from the same shipment of cements and were kept in hermetically-sealed galvanized-iron tanks until used. Chemical analyses of these mixtures indicated that the percentages of the different elements varied as follows:

TABLE IV.—TESTS IN WHICH THE DIFFERENT MIXTURES OF CEMENT WERE USED.

Aggregate.	Mixture used in				Aggregate.	Mixture used in			
	Tension.	Compression.	Permeability.	Yield.		Tension.	Compression.	Permeability.	Yield.
S.....	M 11	M 11	M 12	M 11	Sd. 9....	M 12	M 12	M 13	M 13
Sd. 1.....	M 11	M 11	M 12	M 11	Sd. 10....	M 13	M 13	M 13	M 13
Sd. 2.....	M 11	M 11	M 12	M 11	Sd. 11....	M 12	M 12	M 13	M 13
Sd. 3.....	M 12	M 12	M[1] 13	M 12	Sg. 1.....	M 12	M 12	M 13	M 12
Sd. 4.....	M 12	M 12	M 13	M 12	Sg. 3.....	M 12	M 12	M 13	M 13
Sd. 5.....	M 12	M 12	M 13	M 12	Sg. 4.....	M 12	M 12	M 13	M 13
Sd. 7.....	M 12	M 12	M 13	M 12	Tg. 1.....	M 12	M 12	M 13	M 12
Sd. 8.....	M 12	M 12	M 13	M 13					

[1] M 12 was used in making 1:2 specimens.

CaO, 60.42 to 61.25; SiO_2, 20.40 to 24.36; $Fe_2O_3+Al_2O_3+MnO_2$, 9.48 to 11.31; MgO, 2.56 to 2.85; SO_3, 1.45 to 1.68; loss on ignition, 2.14 to 2.39.

In order that the results of the cement tests may be correlated with the results of tests on mortars, Table IV, showing the tests in which the mixtures were used, is inserted.

METHODS OF MAKING AND TESTING MORTAR SPECIMENS.

Of the experiments performed upon mortars made of the mixed cements and different aggregates, only the tension, compression, permeability, and yield tests will be considered at this time. In all tests the following proportions by weight were employed: 1:2, 1:3, 1:4, and 1:5. All aggregates were dried in the sun before mixing with cement.

The tension tests were made on standard briquettes in accordance with the methods of the American Society of Civil Engineers. The proper percentage of water for gaging the mortar was determined by making trial mixes of 1:2 and 1:5 proportions which were compared with like standard sand mixtures of normal consistency. The percentage of water which

reduced the trial mix to the same consistency as the standard-sand mix was adopted in making briquettes. The percentages of water required for the 1:3 and 1:4 mixes were obtained by interpolation in Feret's consistency equation,

$$W = \frac{2}{3}\left(\frac{P}{S+1}\right) + C.$$

In this equation W is the required percentage of water, P is the normal consistency for the neat cement used, S is the ratio of sand to cement by weight, and C is a constant for the given sand. Values of the latter were gotten by substituting the results of the trial determinations on 1:2 and 1:5 mixes in the above formula and solving for C.

The normal consistency of the mortar for the 3 by 6-in. compression cylinders was determined in a slightly different way from that described above. In these tests it was the endeavor to make the consistency as damp as possible and still produce a mortar sufficiently stiff for making bricks or blocks. Trial batches of 1:2 and 1:5 mortars were mixed in the same manner as for the tension tests and put into a well-oiled 3 by 6-in. cast-iron cylinder mold in four layers, each about $1\frac{1}{2}$ in. deep. Each layer was thoroughly compacted by a cast-iron tamper having a circular base, the diameter of which equaled the radius of the mold. After the mold had been filled and the top leveled it was very carefully slid upward off the specimen. Correct consistency obtained when the specimen presented a moist appearance and settled $\frac{1}{8}$ in. in height.

In fabricating the compression cylinders, sufficient aggregate and cement to make the requisite number of specimens were carefully weighed and placed on a metal mixing board. The materials were then mixed dry with a hoe for four minutes. After adding the proper amount of water the mortar was again turned for four minutes. It was compacted in the molds in the same manner as adopted in the normal consistency test.

The mortar permeability specimens were of the type shown in Fig. 2. Damp sand was first packed in the casting to exclude the mortar. Neat cement of standard consistency was then firmly pressed around the casting as shown in the figure. To afford a more perfect bond for the cement the outside of each casting was grooved. The specimens were completed by im-

mediately filling the molds with mortar mixed in the same way as that used in making compression cylinders.

All briquettes were cured in a moist closet for one day and then placed in a water bath until tested. The compression cylinders were left in the cast-iron molds for 2 days and then removed to a water bath in which they remained 28 days. At this age, those which were to be tested later were taken from the bath and stored on the laboratory floor. Permeability specimens were kept in the molds for six days, during which time they were sprinkled on the exposed surfaces twice a day. After the molds were removed they were sprinkled twice a day

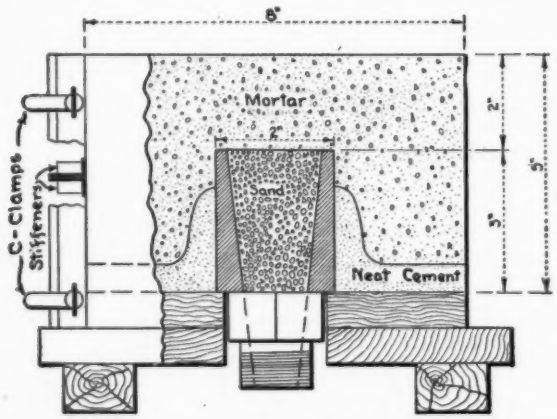


FIG. 2.—Sectional Elevation of Permeability Specimen.

on all surfaces. When the permeability specimens were one day old the surfaces uppermost in the molds were vigorously scrubbed with a wire brush to remove any excess mortar or laitance. Two days before testing they were submerged in tubs. When four weeks old the sand was removed from the castings and the mortar surfaces within were carefully chipped with a cold chisel. The castings were then refilled with clean sand, and the specimens were placed upon the testing apparatus.

The apparatus used in testing the permeability specimens is shown in Fig. 3. Air pressure was used to force the water into the specimens. In order that a record might be had of the amount of water entering the test specimens, glass tubes *g*

fitted with scales *s* were attached to the vertical pipes *p* on the apparatus so that the height of the water column could be easily read. Observations of time, pressure, and tube readings were made several times during the first day and twice a

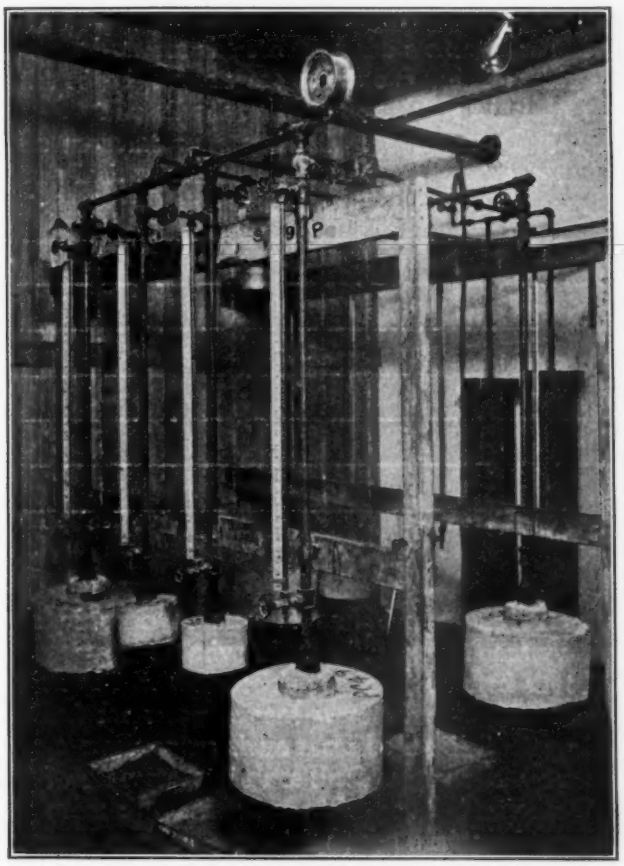


FIG. 3.—Apparatus Used in Making Permeability Tests.

day thereafter for one week. A pressure of 40 lb. per sq. in. was used for three days. If there was considerable leakage at this pressure, a reduction was made to 10 lb. per sq. in. for the remainder of the test period. Some of the specimens of

1:5 proportions leaked so rapidly under the high pressure that no attempt was made to get a record. In such cases the pressure was immediately reduced to 10 lb. per sq. in.

For comparative results this form of permeability specimen is cheap, easily made, and quickly adjusted on the apparatus. No difficulty was experienced from leaks around the castings or at the 2-in. unions by which the castings were coupled to the testing apparatus. Special care was taken, however, to prevent the latter by using a new rubber gasket with each specimen. Owing to an over-zealous helper, more mortar was removed from the interior of some of the specimens than necessary. On one or two the minimum thickness between casting and bottom of specimen was only $1\frac{3}{8}$ in. The average thickness per set of four layers at this place varied from $1\frac{9}{16}$ to $2\frac{3}{16}$ in. A study of the effects of these variations in depth upon leakage did not show that any relation existed. This was doubtless due to the fact that the average thickness of the concrete between the end of the casting and the bottom of the specimen was considerably greater than the minimum. It is probable that the average thicknesses of the mortar at this place for the entire series of specimens would vary between $1\frac{7}{8}$ and $2\frac{1}{4}$ in.

All briquettes were broken in a Riehlé automatic shot machine equipped with metal-roller grips. Loads were applied at a rate of 600 lb. per minute. With few exceptions, the average results obtained from four specimens are indicated by the conventional signs on the diagrams. In addition to tests covering the ages shown in the figures, two and five year tests are being made on the mortars of 1 : 3 proportions.

In testing cubes and cylinders a spherical bearing-block was employed underneath all specimens. If the top surface of a test specimen was uneven the high spots were taken off with a Vixen rasp. Both tops and bottoms of all specimens were bedded on blotting paper. In order that the axes of specimens and bearing-blocks should coincide, a template was employed for centering the specimens on the block. The speed of the pulling head of the testing machine in these tests was 0.13 in. per minute. In nearly all cases the points on the diagrams represent the average results of three specimens.

The purpose of the yield test is, primarily, to determine

the amount of mortar which may be made from given amounts of aggregate and cement, but if the specific gravities of the materials are known, the density and weight per cubic foot of the mortar may also be found. The test was made by mixing three pounds of dry aggregate and cement into a mortar, tamping the latter into a cast-iron cylinder $3\frac{3}{8}$ in. in diameter and measuring the volume of the mortar to 0.0001 cu. ft. The consistency, method of mixing and molding, and the method of compacting were the same as used in making the compression cylinders. The weight of the materials before and after mixing and the volume of the dry aggregate before mixing were also ascertained. In computing the results, corrections were made for the moisture content in the aggregate and for the losses in the mixing. Two determinations were made upon each proportion. In general, the two results differed less than one per cent; in many tests they checked to the third place of decimals.

The values of yield plotted in Figs. 7 and 8 were computed by dividing the volume of mortar by the volume of compacted dry aggregate. If the volume of mortar which may be made from a given loose volume of aggregate is desired, the values given should be reduced by the following ratios:

S.	0.99	Sd. 8	0.95
Sd. 1	0.89	Sd. 9	0.94
Sd. 2	0.86	Sd. 10	0.95
Sd. 3	0.91	Sd. 11	0.96
Sd. 4	0.90	Sg. 1	0.77
Sd. 5	0.89	Sg. 3	0.79
Sd. 7	0.89	Sg. 4	0.75
Tg. 1	0.80		

As an interesting illustration, consider the amount of 1:4 mortar which can be made from Tg. 1. The diagram in Fig. 8 indicates that a cubic yard of well-compacted tailings would produce 1.09 cu. yd. of mortar. If the cubic yard of tailings was measured loose, only 0.872 cu. yd. of mortar could be made.

The term density as used in this paper means the ratio of the sum of the absolute volumes of cement and sand to the volume of mortar. The absolute volumes of sand and cement per unit volume of mortar will be denoted by s and c, respectively. To obtain s, the absolute volume of the sand in the mix

was first determined by dividing the weight of the sand by its specific gravity times the weight per cubic foot of water; then this quotient was divided by the volume of the mix. By the same process c was computed. Density, therefore, is equal to $c+s$.

RESULTS OF STRENGTH TESTS.

The results of the strength tests will now be considered. Figs. 4, 5 and 6 show strengths of the four mixes at different ages from seven days to one year. It will be at once noted that many of the 1 : 2 and 1 : 3 mixes have less strength at one year than at six months. The decrease appears more marked in the results of the compression tests than in the tension test values. The mortars of Sd. 4 and Tg. 1 are the only ones in which all mixes show a consistent growth in compressive strength during the year; those of Sd. 5, Sd. 11 and Sg. 3 are the only ones which, in all proportions, exhibit a regular increase in tensile strength. A further comparison of the strength-time curves for these aggregates also shows that the mortars from Sd. 4 and Sd. 5 only are of lower strength than the standard sand mortars. This result is not surprising if one considers the mechanical analyses of these sands given in Table II. From the table it will be observed that over 60 per cent of each of these sands passed a No. 50 sieve, a fact which will give some notion of their fineness.

In Figs. 7 and 8 both tensile and compressive strengths at 60 days have been plotted against the ratio of sand to cement. With the exception of the curves for Tg. 1 the relation of the two curves is what might be expected. On account of the lack of fine particles in Tg. 1 the 1 : 5 mortar cylinders were full of pockets and consequently possessed little strength. Since the ratio of exposed surface to volume for the briquettes was very much greater than for the cylinders, the troweling done in smoothing off these surfaces made the briquettes denser than the cylinders and was, without doubt, the cause for the discrepancy between tension and compression tests on the 1 : 5 mix of this material. Considering the sands alone, the ratios of compressive to tensile strength at 60 days for the different mixes vary between the following limits: 7.3 to 9.9 for 1 : 2 mixes, 5.6 to 8.3 for the 1 : 3 mixes, 6.0 to 7.8 for the 1 : 4

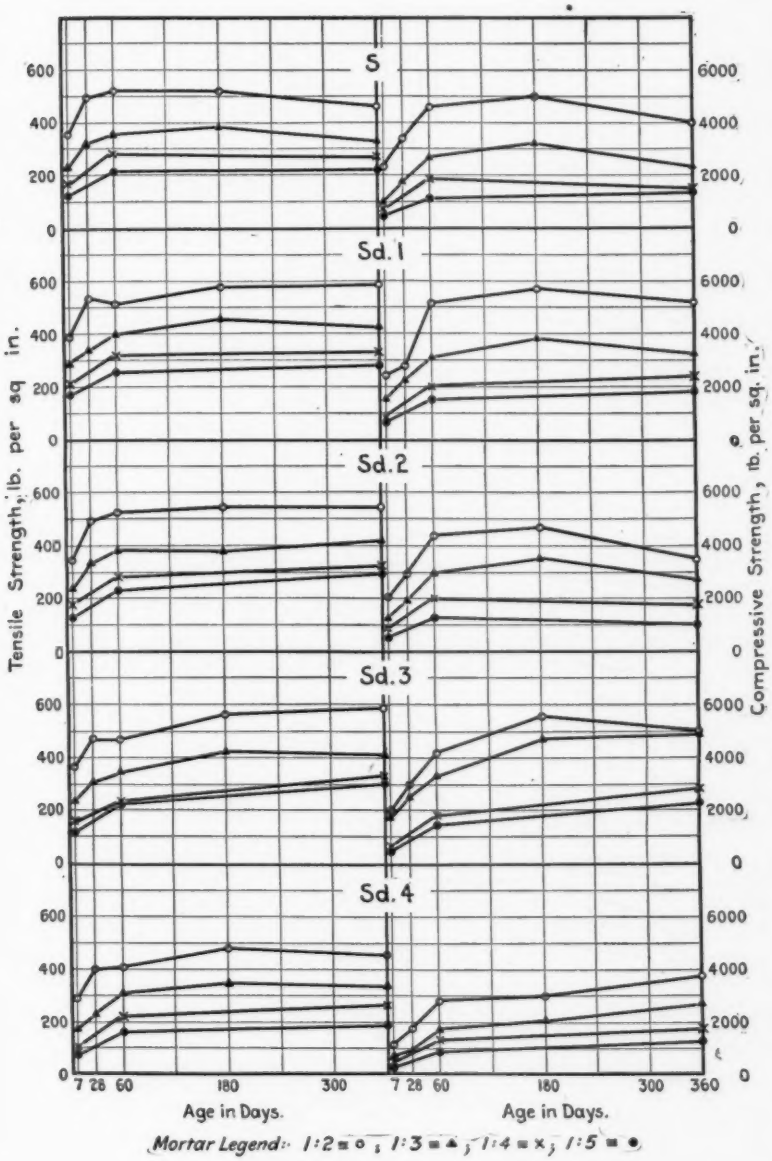


FIG. 4.—Strength of Mortars at Different Ages.

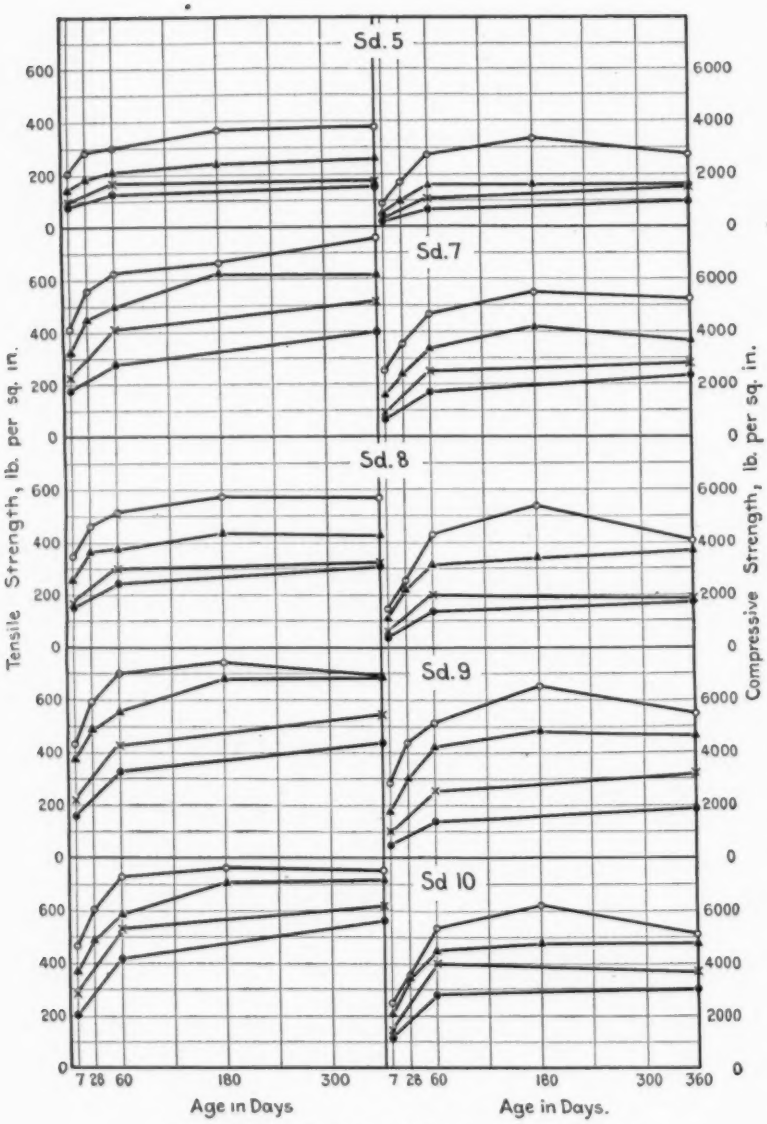


FIG. 5.—Strength of Mortars at Different Ages.

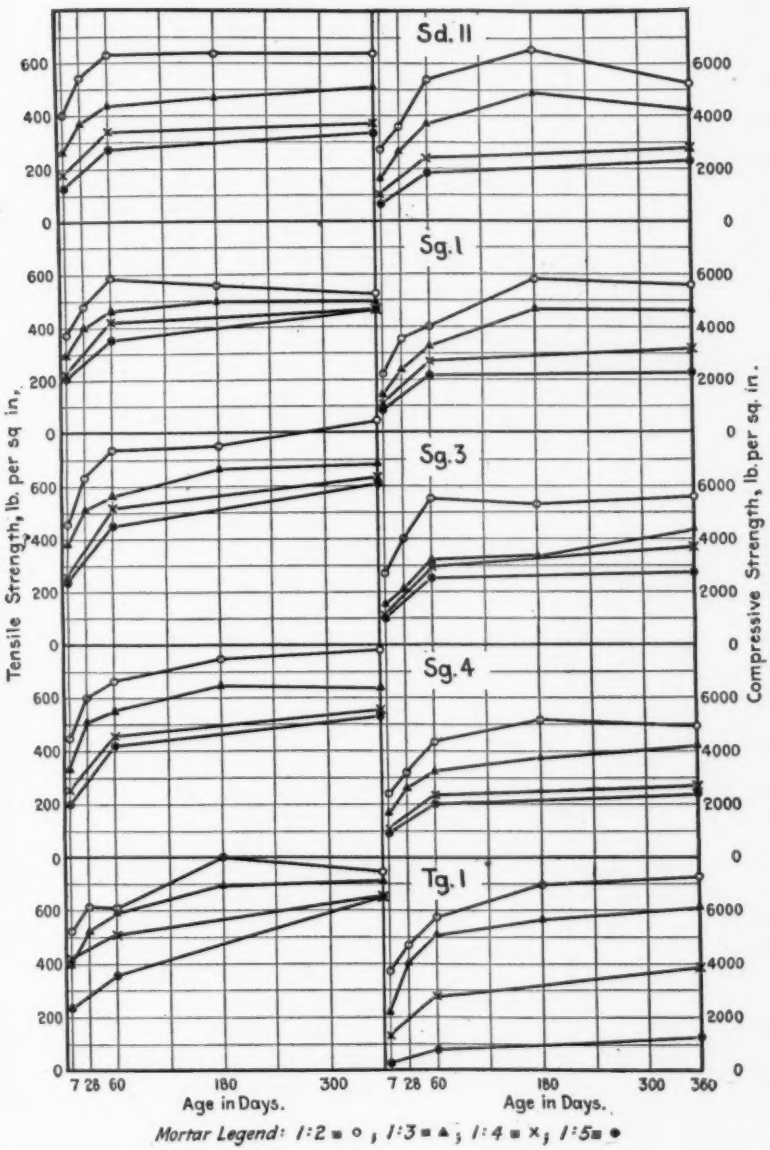


FIG. 6.—Strength of Mortars at Different Ages.

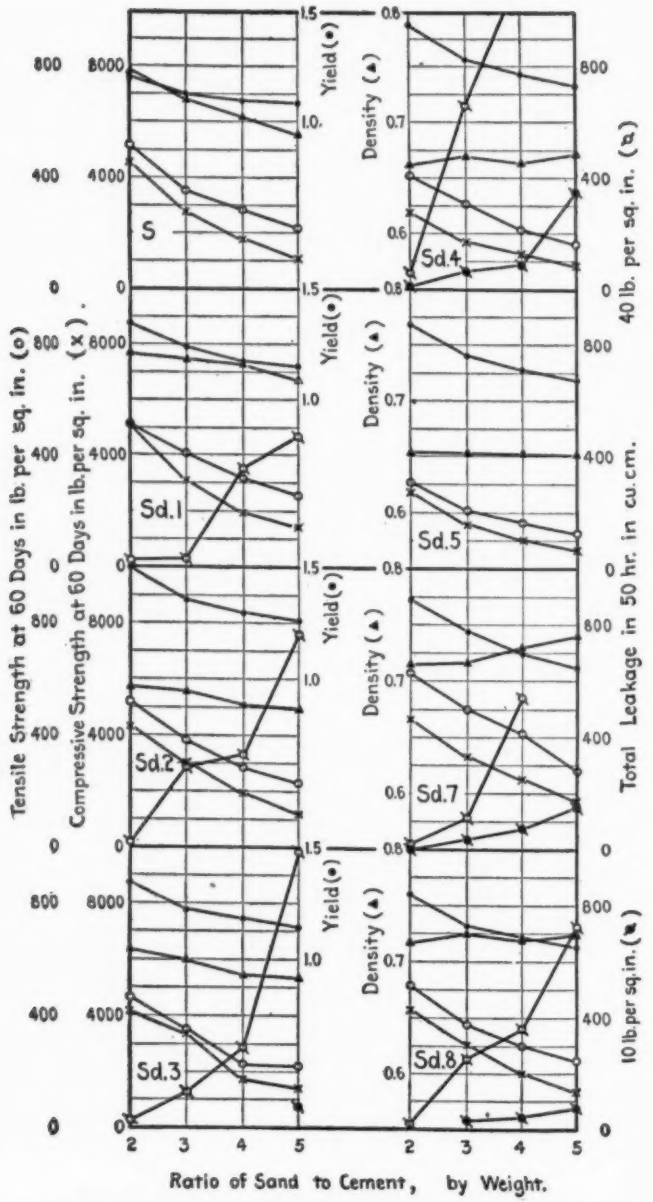


FIG. 7.—Influence of Proportions of Sand to Cement upon Strength, Density, Permeability, and Yield.

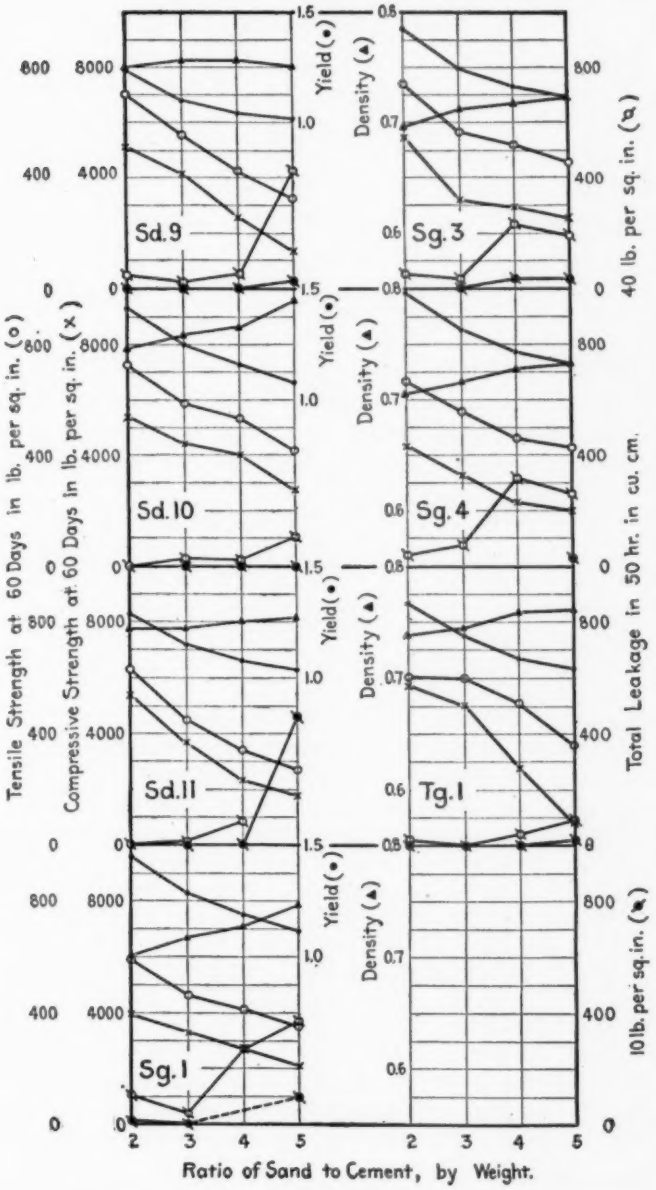


FIG. 8.—Influence of Proportions of Sand to Cement upon Strength, Density, Permeability and Yield.

mixes, and 4.2 to 6.7 for the 1 : 5 mixes. In the above order the average ratios are 8.3, 7.7, 6.6 and 5.6, respectively.

According to the experiments of Feret[1] the following law obtains:

"For all series of plastic mortars made with the same cement and of inert sands, the resistance to compression after the same time of set under identical conditions is solely a function of the ratio $\frac{c}{e+v}$ or $\frac{c}{1-(c+s)}$, whatever may be the nature and size of the sand and the proportions of the elements —sand, cement, and water—of which each is composed."

In the above law e and v represent the volumes of the water and air voids in a unit volume of mortar; the other symbols have been previously defined. In Fig. 9, values of both the tensile and compressive strengths of the different mortars have been plotted against the ratio $\frac{c}{1-(c+s)}$, and against the ratio $\left(\frac{c}{1-s}\right)^2$. Feret, as a result of his tests derived the following relations:

$$P=J\left[\frac{c}{1-(c+s)}-0.1\right] \quad \text{and} \quad P=K\left(\frac{c}{1-s}\right)^2,$$

in which P is the compressive strength in pounds per square inch and J and K are constants depending upon the consistency, character of the cement, and age of specimens. For a series of tests his results indicate a value of $K=28{,}000$ lb. per sq. in. The equations of the lines in the lower portion of Fig. 9 are of the form:

$$P=J\left[\frac{c}{1-(c+s)}-0.19\right] \quad \text{and} \quad P=K\left[\left(\frac{c}{1-s}\right)^2-0.012\right];$$

J and K equal 8150 and 26,000 lb. per sq. in., respectively.

The points in the upper portions of Fig. 9 do not lie so close to the lines. Inspection of the figure shows that this divergency is most marked for the 1 : 2 mixes. It is also noticeable that the points for the limestone screenings lie, in general, considerably above the curves. This discrepancy may be due to the existence of cementitious properties in the screenings.

[1] *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, 1897, p. 1604; also, Taylor and Thompson's "Concrete: Plain and Reinforced," p. 140.

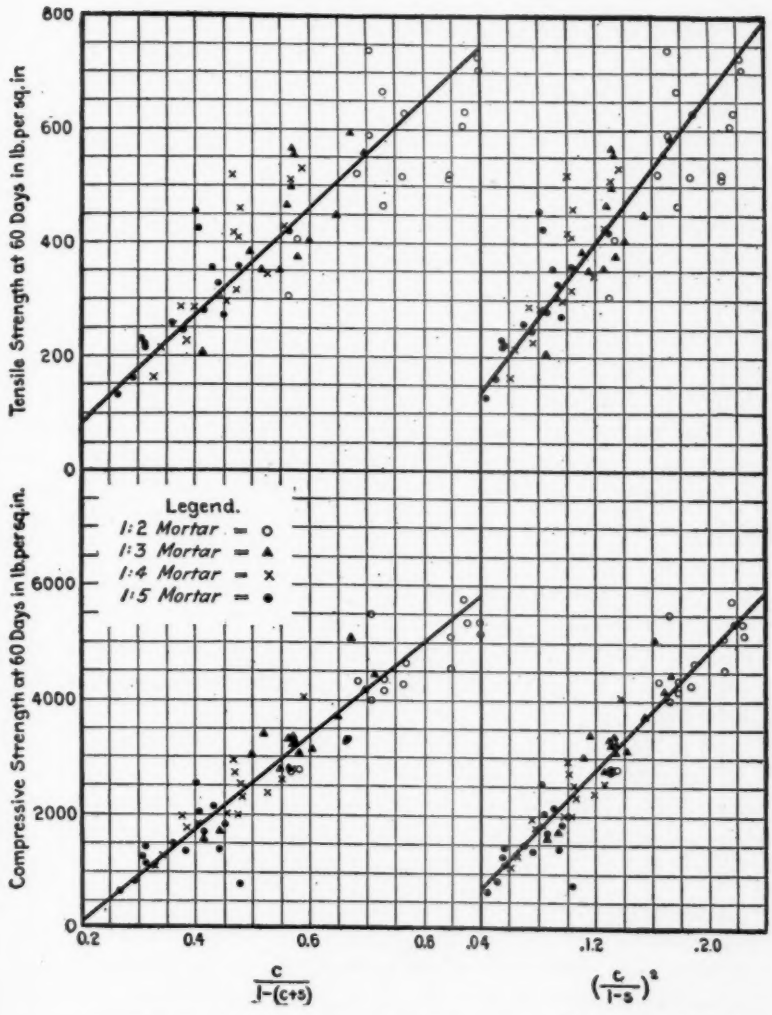


FIG. 9.—Relation between Strength and Ratios $\frac{c}{1-(c+s)}$ and $(\frac{c}{1-s})^2$.

It should also be noted that the percentages of water employed in the yield tests were slightly greater than those used in making briquettes, so that the values of the ratios $\frac{c}{1-(c+s)}$ and $\left(\frac{c}{1-s}\right)^2$ do not strictly apply to the mortars from which briquettes were made. The equations of the curves drawn in the upper half of Fig. 9 are respectively:

$$T = 935\frac{c}{1-(c+s)} - 100 \quad \text{and} \quad T = 3260\left(\frac{c}{1-s}\right)^2;$$

here T is the ultimate tensile strength in pounds per square inch.

Diagrams for the transverse strengths of these mortars plotted against the above ratios show a scattered field quite similar to the diagrams containing the tension test data.

An interesting comparison of the relative economy of different sands and mixes of the same sand is afforded in Fig. 10. In computing the costs of the mortar, cement was estimated at $1.50 per barrel and sand at $1.25 per cubic yard. Only the cost of the materials was considered; no allowance was made for the cost of handling, mixing, placing, finishing, or form work—factors which vary greatly with the character of the construction. If the cost of these items be included, the comparisons will accentuate the superiority of the stronger sands and richer mixtures.

The computation involved in laying out this diagram was very simple. The quantities of sand and cement required for one cubic yard of mortar were determined from the yield and the cost calculated. By dividing the compressive strength at 60 days by the cost of the mortar in dollars per cubic yard, the lengths of the heavy lines in the diagram were determined. It will be noted that even from the standpoint of strength the richest mix is not always the most economical; for example, the 1:3 mix of Tg. 1 is the most economical of any in the figure and the 1:4 mix of Sd. 10 is second. In a practical problem, if the cost of items other than materials is a large proportion of the total cost of the mortar, the superiority of the 1:2 mixes or in some instances even richer mortars would be apparent.

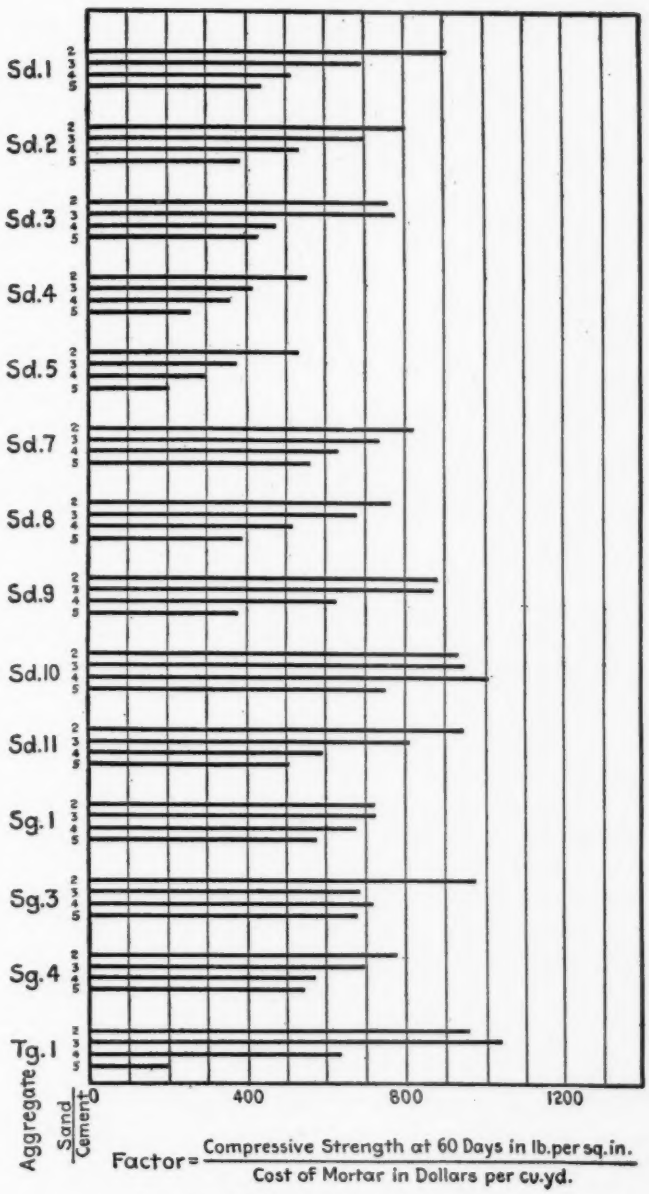


FIG. 10.—Ratios of Strength to Cost.

RESULTS OF PERMEABILITY TESTS.

Referring again to Figs. 7 and 8, one will note the marked difference in permeability of rich and lean mixes. The leakage under 40 lb. per sq. in. pressure for most of the 1:2 mixes was so small that the water evaporated from the outside surfaces of

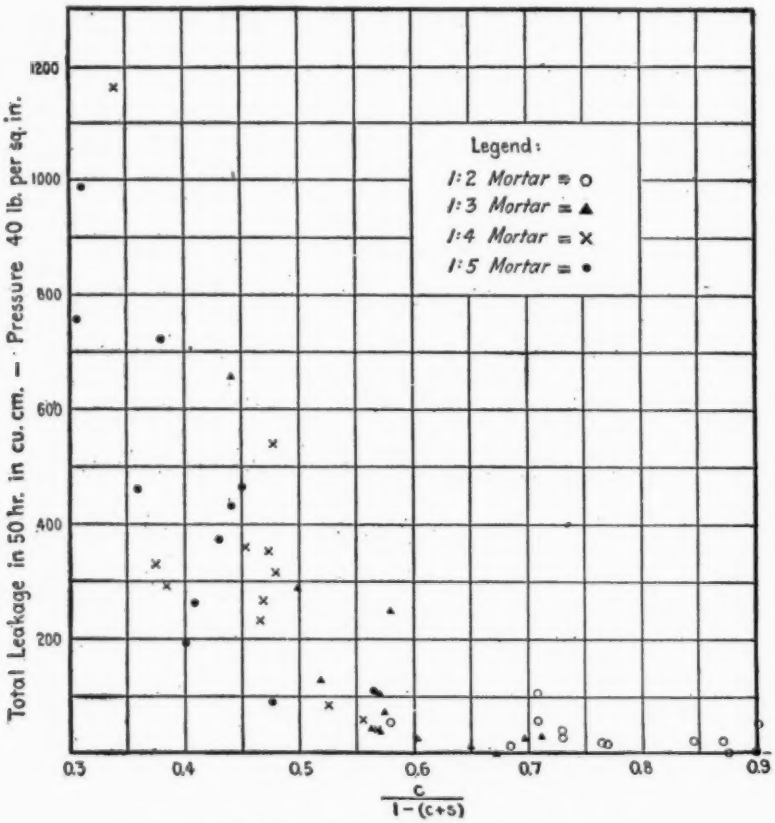


FIG. 11.—Relation between Leakage and $\frac{c}{1-(c+s)}$.

the specimens as rapidly as it came through, so that the only evidences of flow were the readings of the heights of the water columns. Some of the curves on Fig. 8, however, show a decrease in leakage with a decrease in proportion of cement. It will also be observed that density increased wherever this phe-

nomenon was observed. These observations are in accord with the common belief that both the richness of the mix and its density affect the permeability. Furthermore, if leakage-density curves be plotted from the values in the diagrams, it will be found that for the same density the permeability decreases with the increase in cement.

In Fig. 11, total leakage in 50 hours has been plotted against the ratio $\frac{c}{1-(c+s)}$. The field of points is scattered but there is evidence of relation. For the points shown, an hyperbola with asymptotes parallel to the axes of the diagram seems to be the form of the locus.

CONCLUSIONS.

As a result of these tests it appears probable that the laws of Feret have a wider range of application than to compressive strength alone. It is quite likely that both the tensile and transverse strengths obey similar laws. There also seems to be a relation between leakage and Feret's ratios.

The experiments illustrate the value of the well-graded sands, but no well-defined relation between strength and uniformity coefficient, percentage of voids, or percentage of silt appears.

Inasmuch as a continued increase in strength of mortars after 60 days does not seem at all certain, both from these tests and many others, too great emphasis cannot be laid upon the importance of records extending over long periods of time. In such records the results of compression tests appear to be fully as important as the tension-test values.

For compression tests of mortar a cylindrical form of specimen with a height equal to twice its diameter is much more satisfactory than a cube.

Attention should also be directed to the wide variation in the yield depending upon the method of measuring the volume of the aggregate. This is especially noteworthy in the case of aggregates like screenings.

If economy is to obtain in constructions in which strength is an important consideration, an investigation of the relation of strength to total cost, for the different available aggregates and for various mixes of such aggregates, is desirable.

TESTS OF REINFORCED CONCRETE SLABS UNDER CONCENTRATED LOADING.

By A. T. Goldbeck.

Several years ago the United States Office of Public Roads expanded its engineering activities to include a limited amount of work in connection with highway bridges. One of its first efforts in this direction was to encourage local highway officials to replace the great number of unsafe and unsightly short-span wooden bridges and culverts with permanent structures of reinforced concrete. In order to better disseminate information concerning this subject, many typical designs were prepared together with tables showing suitable dimensions and reinforcement for both slab and beam superstructures.

One of the first difficulties which the engineers of the office encountered in making computations for these designs and tables, was that of deciding upon some reliable assumption concerning the distribution of stress in reinforced concrete slabs under concentrated wheel loads. Careful search through engineering literature failed to reveal any experimental data upon which to base assumptions relating to this subject. It was also found that widely variant ideas regarding the distribution of the concentrated loads were held by different designers. Under the circumstances it was necessary to prepare tentative designs based on assumptions which appeared most reasonable. It was very evident, however, that any tests which could be made to show a definite relation between concentrated loads and the stresses which they would produce in reinforced concrete slabs would be of considerable value, not only to bridge designers who have to deal with roller and tractor loads, but to all engineers and architects who have to provide for isolated loads of any considerable magnitude upon reinforced concrete slabs.

When the value of an investigation of this character became evident a series of tests was planned, and although at this time but partially completed, the results obtained are presented in

the hope that the length of time required for the completion of this investigation will be materially decreased, by enlisting the services of other interested workers who may have either results or ideas to offer. In other words, it is desired that these results be considered merely as a contribution toward the final solution of the problem.

When the engineer is confronted with the design of a reinforced concrete slab to be subjected to a concentrated load, his fundamental consideration is the width of slab that may reasonably be counted as effective in carrying the load. It is necessary for him to assume the value of what may be called the effective width of slab when using the ordinary theory of rectangular beam design, and since it is probable that this width varies with the percentage of longitudinal and transverse steel, span, depth, and kind of concrete mixture, it will be seen that the number of tests required to furnish a satisfactory basis for this assumption will be very large. It is hoped, however, that the tests to be described will at least contribute toward the desired end.

DESCRIPTION OF SPECIMENS.

All specimens were made of concrete mixed in the proportion 1 : 2 : 4, to a consistency ordinarily described as "quakey." The cement complied with the United States Government specifications for Portland cement; the sand was a fairly well graded Potomac River sand, and the gravel was clean, sound and well graded from $\frac{1}{4}$ up to $\frac{3}{4}$ in. One-half-inch plain round steel rods, having a yield point of 38,800 lb. per sq. in. and a tensile strength of 73,000 lb. per sq. in., were used exclusively for reinforcement. Compression cylinders of the same concrete, 8 in. in diameter and 16 in. high, were molded at the time the slabs were made.

The slabs were molded on heavy oiled paper, laid on the floor of the laboratory. The center of the steel was placed 1 in. from the floor, so that the total depth of the slab was 1 in. greater than the effective depth. The present series of tests includes the specimens described in Table I.

Within a few days after each slab was made, plates of brass $\frac{1}{2}$ in. square and $\frac{1}{8}$ in. thick, containing a small hole drilled

with a No. 55 drill, were cemented to the top in carefully spaced rows. The drill holes in these plates were placed exactly 8 in. apart in order that they might be used in connection with an instrument designed to measure very slight changes in their spacing. Some of the reinforcing rods were likewise drilled with a No. 55 drill and the drill hole was protected from the concrete while pouring, by means of insulating tape and a cork. The cork and tape were later burnt out in order to expose the drill hole in the steel. Slab No. 679 was provided on the bottom with small cast-iron blocks wired in contact with the rods and each block was drilled for deformation measurements. Measurements were taken both at right angles to the supports

TABLE I.—DESCRIPTION OF REINFORCED CONCRETE SLABS.

Slab No.	Dimensions, ft.		Depth, in.		Approximate Weight, lb.	Percentage of Steel.	
	Length.	Breadth.	Total.	Effective.		Longitudinal.	Transverse.
679	13	6	7	6	6830	0.77	....
705	9	7	5	4	3940	0.91	....
706	9	7	5	4	3940	0.91	0.41
730	9	7	6	5	4720	0.91	....
736	9	7	4	3	3160	0.60	....
737	9	7	7	6	5520	0.75	0.33

and parallel with them, in sufficient numbers to determine the magnitude and distribution of the deformation in each direction.

DESCRIPTION OF APPARATUS.

The deformation measurements were taken in the concrete and steel by means of a strain gage of the type designed by H. C. Berry. It consists of a rigid frame carrying a fixed conical point at one end and a movable conical point at the other end. The motion of the movable point is multiplied five times by means of a bell-crank lever and its amount is indicated on a graduated dial. By very careful manipulation an accuracy of

0.0001 in. in 8 in. may be obtained. In using this instrument, the conical points are simply inserted into the No. 55 drill holes and the dial reading is taken.

For measuring deflections, a special instrument was designed. It consisted of a surface testing dial reading to 0.001 in., mounted at the center of a white pine board, which was shod at the lower edge with grooved pieces of steel. While being used the board was placed on edge in the direction of the span and made to rest upon steel rods having rounded upper ends. These rods were cemented in a vertical position over the supports. A movable plunger actuating an indicator on the dial rested in contact with a drilled brass plate, cemented to the top of the slab at the center line. Deflection readings were taken at a number of places throughout the length of the slab.

Loads were applied by means of a general testing machine of 200,000-lb. capacity. The weighing table of the machine in use at the Office of Public Roads is fitted with long extension arms for testing narrow beams up to 16 ft. in span length. In order to investigate a large reinforced concrete slab in a machine of this type, it is necessary to mount the specimen transversely across one of the extension arms. For this purpose two 15-in., 42-lb. I-beams were supported on one of these arms. In testing slab No. 679, two 6-in., 12¼-lb. I-beams were laid across these, in order to serve as supports for the slab. For all other slabs, the 15-in. beams acted as supports. For applying the load, two 18-in. 55-lb. I-beams were used. They were bolted together and extended from the extreme end of one of the extension arms over the moving head of the machine to the center of the slab. One end of these I-beams rested on bearing blocks, which in turn were supported by a 15-ton screw jack, mounted on a concrete support. The other end—the end applying the load—rested on the slab to be tested. Loads were applied on the 18-in. I-beams by the moving head of the machine, through a 2-in. loop-welded eye; and by means of the screw jack the load-applying beams were maintained in a horizontal position. It was necessary to counterbalance the weight of the slab and its supporting I-beams to prevent the overbalancing of the machine.

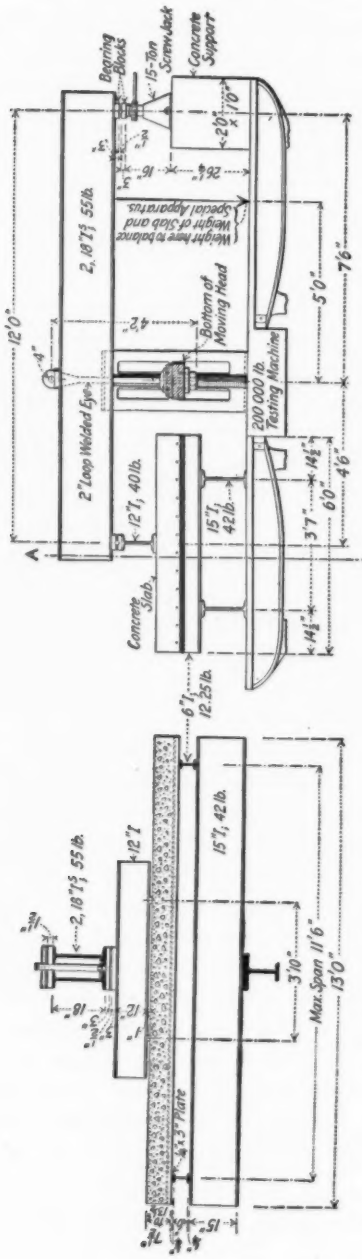


FIG. 1.—Showing Attachment to General Testing Machine for Testing Full-Size Bridge Slabs under Concentrated Loading, and Method of Mounting a Slab.

METHOD OF TESTING.

The exact method of mounting the specimens indicated in Fig. 1 was slightly modified in order to obviate the danger attending the use of the rocking supports. It is probable that a very slight error has resulted, owing to the small drag of the supports, which tend to rock out of a vertical position when the load is applied. This error, however, is of inconsiderable magnitude. To insure uniform bearing, the specimens were



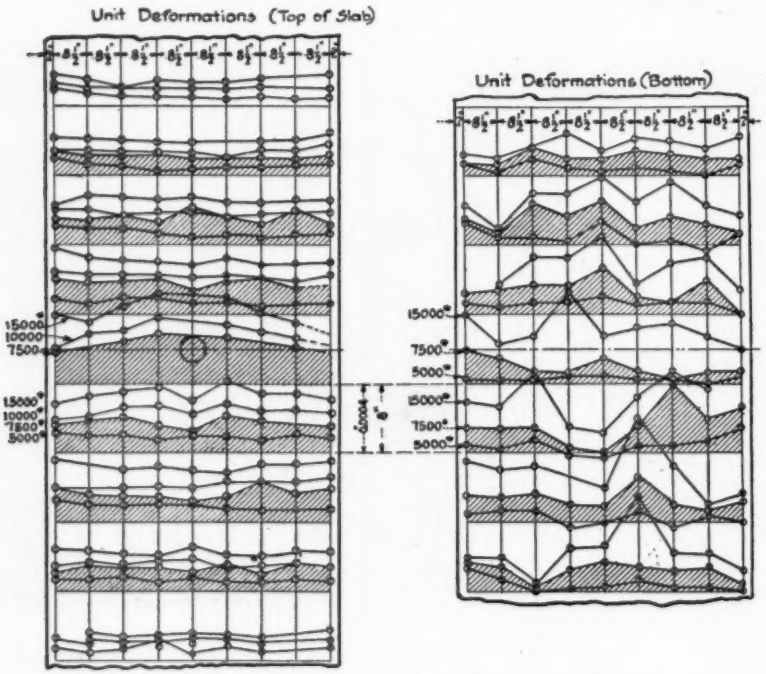
FIG. 2.—Test of Reinforced Concrete Slab under Concentrated Load. Span = 6 ft. Width = 9 ft.

lowered upon a soft mortar mixture placed on the I-beam supports, and this bedding was allowed to harden for one day before the slab was tested. Loads were applied on the slabs over a bearing area 6 in. in diameter and containing 28.3 sq. in., with the exception of slab No. 679, in which the bearing block consisted of one-half of a vitrified paving block having a bearing area of 18 sq. in. A complete set of deformation and deflection readings were taken for each increment of load applied.

Fig. 2 shows a slab in position for testing.

RESULTS OF TESTS.

Some typical results of the deformation and deflection readings are given in graphical form in Figs. 3 to 8, inclusive. The ordinates to the curves of unit deformation show the amount of this deformation in various parts of the slab. The values plotted represent the mean unit deformations in gage lengths of 8 in., with the measurements taken at right angles to the



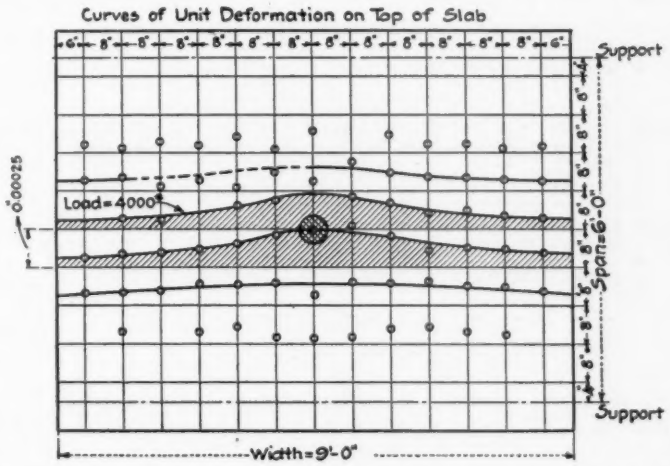
Span = 11 ft. 6 in. Width = 6 ft. Reinforcement = 0.77 per cent.

FIG. 3.—Slab No. 679.

supports. The base line of each curve marks the position of the line of brass plates between which the deformation measurements were taken. The position of the load is marked by means of a cross-sectioned circle. The curves of deformations which most nearly represent conditions, under the load causing a working stress at the center, are cross-sectioned, and on some of the plates curves are plotted, showing the unit deforma-

tions caused by loads both greater and less than the working load.

Considering first the deformation curves in Figs. 4 to 8, inclusive, it will be noted, as might be expected, that the greatest deformation occurs under the load, and that as the supports are approached the deformations become smaller. The local effect of the load is very perceptible in producing deformation in the slab. Although the deformations at the sides of the slab are small, yet there is a very perceptible deformation, even at a distance of $4\frac{1}{2}$ ft. on each side of the load, or over



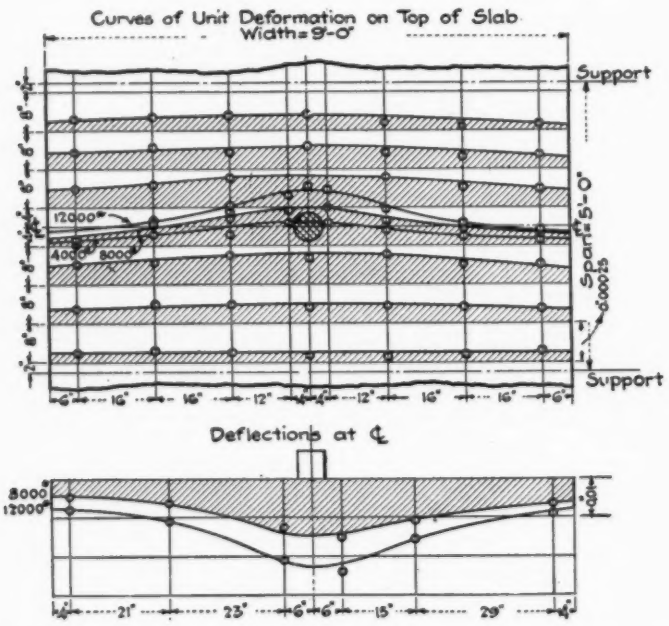
Span = 6 ft. Effective Depth = 4 in. Reinforcement = 0.91 per cent.

FIG. 4.—Slab No. 705.

a total width of 9 ft. This indicates that even at $4\frac{1}{2}$ ft. from the load the slabs investigated exerted considerable resisting moment. In a general way the maximum deformations in the same slab seem to be proportional to the loads applied. The deformations on the top of the slabs parallel to the supports showed a compression very small in magnitude.

An estimate of the width of each slab that might reasonably be considered as carrying the load—assuming a uniform distribution of the safe working stress over this width—was obtained from the curves of deformation. Since the resisting moment of a slab is dependent on the stresses in the top fibers,

and these in turn are measured by the unit deformations of these fibers, the resisting moment is proportional to the ordinates to the curves of unit deformation at the center of the slab. If the unit deformation be considered as uniformly distributed, with a constant ordinate equal to the maximum ordinate in the actual curves of deformation, the width of the slab, having a resisting moment equal to that of the slab tested, may be



Span = 5 ft. Effective Depth = 5 in. Reinforcement = 0.91 per cent.

FIG. 5.—Slab No. 730.

obtained by equating the area of the theoretical rectangle of deformation to that of the actual curves of deformation. In this way the effective widths of the slabs given in Table II were obtained.

These values seem to indicate that the effective width of the slab hovers in the vicinity of the span length. This can not be stated as a general proposition, for doubtless factors other than the span length, such as depth, percentage of rein-

forcement, etc., have influence on the effective width. The values given above are merely approximate estimates and are not exact. To obtain correct values for the effective width, it will be necessary to have the slab of such a width that the deformations vanish at the sides, and in the slabs tested this is not the case. Moreover, as before stated, many more tests will have to be performed before any definite conclusion can be drawn regarding the influence of all of the variable factors on the stress distribution. It is interesting to note that when the ordinary straight-line formula for resisting moment ($M = f_c jkbd^2 \div 2$) of a rectangular reinforced concrete beam is used, and the concrete is considered as governing this resisting moment, the effective width of slab obtained, when the modulus of elas-

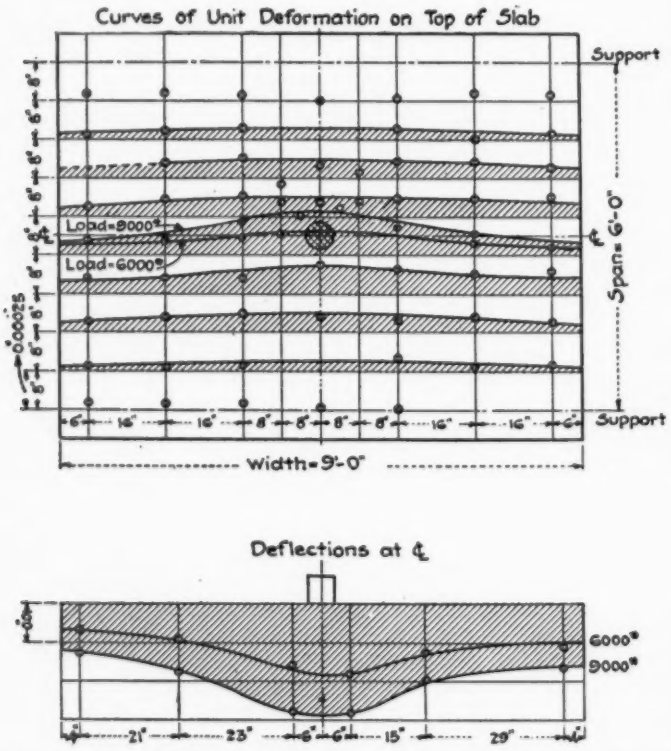
TABLE II.—ESTIMATES OF THE EFFECTIVE WIDTHS OF SLABS UNDER WORKING STRESSES.

Slab No	Span, ft.	Effective Width, ft.		Ratio of Effective Width (from curves) to Span.
		From Curves.	$b = \frac{M}{\frac{f_c}{2} jkd^2}$	
705	6	5.25	4.66	0.9
730	5	5.5	5.0	1.1
	6	5.75	5.92	0.96
737	5	6.0	6.0	1.2
	6	7.16	5.25	1.2

ticity of the concrete is taken at 2,000,000, checks in most cases with that obtained from the curves. These widths are given in the second column of Table II under "Effective Width," and were calculated using values for f_c corresponding to the maximum unit deformation under the load, taken from the cross-sectioned curves which represent very closely the conditions that obtain under working loads.

The curves of unit deformation on the bottom of slab No. 679, shown in Fig. 3, are of principal interest in showing that it is almost useless to attempt to obtain the stress distribution and effective width from readings in the steel. It will be noted that great irregularities occur in these curves. Where peaks in the tension curves occur, it was discovered that cracks

had formed in the concrete within the spaces over which those particular measurements were taken, and indicate a large stretch in the vicinity of the cracks. There is a much smaller stretch on each side of the cracks where the concrete assisted the steel in tension.



Span = 6 ft. Effective Depth = 5 in. Reinforcement = 0.91 per cent.

FIG. 6.—Slab No. 730.

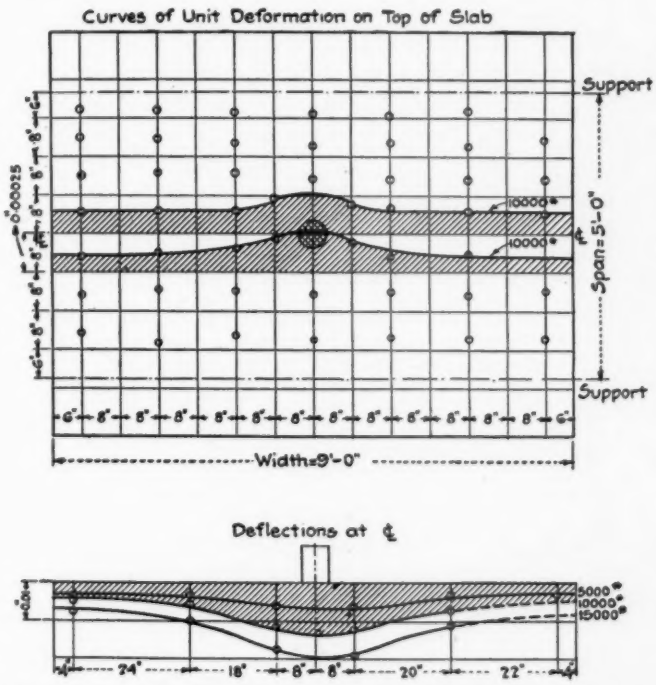
CURVES OF DEFLECTION.

The curves of deflection are of principal interest in showing the shape assumed by the center line of the slab parallel to the supports when the loads are applied. As in the case of the deformation curves, the deflection curves show the local effect of the load in deforming the slab. The maximum deflections

for the different loads on the same slab seem to be approximately proportional to the loads applied, when the loads are not excessively large.

MAXIMUM CENTRAL LOAD AT FAILURE.

The maximum loads applied to the centers of the slabs at failure are given in Table III.

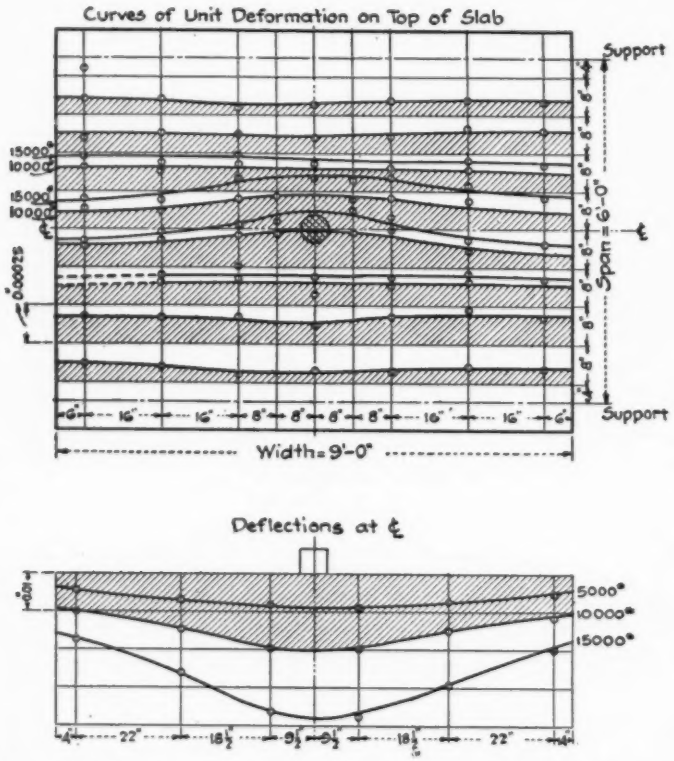


Span = 5 ft. Effective Depth = 6 in. Reinforcement = 0.75 per cent. Transverse Reinforcement = 0.33 per cent.

FIG. 7.—Slab No. 737.

The shape of the cracks on the bottom of each slab is shown in Figs. 9 and 10. Slab No. 679, although without any transverse steel whatever, cracked almost in a straight line across the center from side to side, and failed probably by tension in the steel. No. 706, a wide slab tested on a short span, failed, as might be expected, by shear. The bearing

cylinder, 6 in. in diameter, punched a hole in the center of this slab at failure, and the concrete was badly cracked under the load. The cracks extended on each side of the load over a width of about 5 ft. No. 730, tested on a 6-ft. span, failed probably by tension in the steel, and unlike No. 679, two diagonal cracks



Span = 6 ft. Effective Depth = 6 in. Reinforcement = 0.75 per cent. Transverse Reinforcement = 0.33 per cent.

FIG. 8.—Slab No. 737.

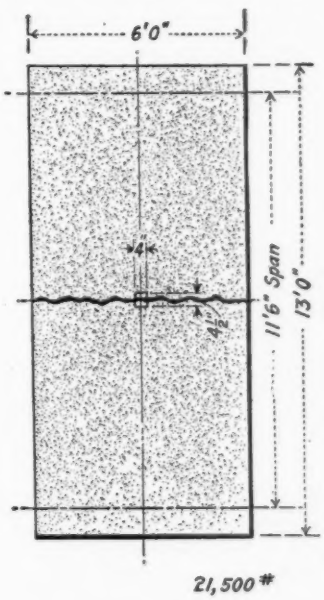
were formed extending over a width of about 5 ft. No. 736 also failed by tension. It was the thinnest slab tested, and in addition to the diagonal cracks, others developed at right angles and parallel to the supports. No. 737, like No. 730, and notwithstanding the fact that it was reinforced transversely with

TABLE III.—CENTRAL LOADS AT FAILURE.

Slab No.	Span, ft.	Bearing Area, sq. in.	Central Load, lb.
679	11.5	18	21 500
706	3	28.3	42 800
730	6	28.3	24 700
736	6	28.3	7 560
737	6	28.3	34 200

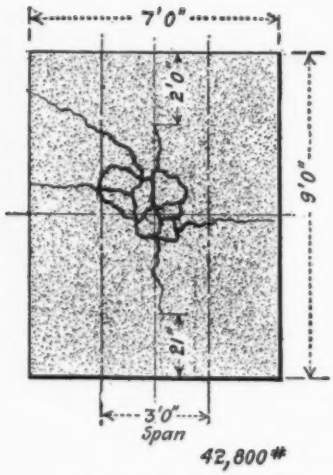
NOTE: See Table I for description of slabs.

0.33 per cent of steel, developed diagonal cracks, extending in this case over a width of about 6 ft. The width over which these tension cracks extend in all of the slabs tested is very

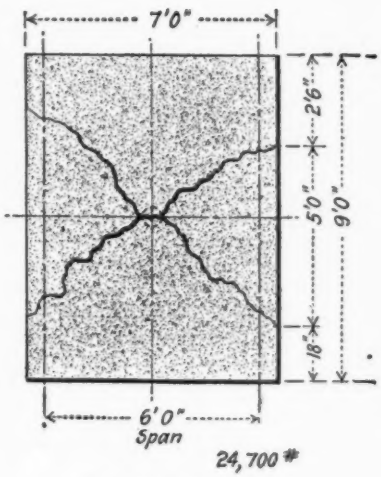


SLAB NO. 679.
FIG. 9.—Bottom of Slab after Failure, showing Shape of Cracks.

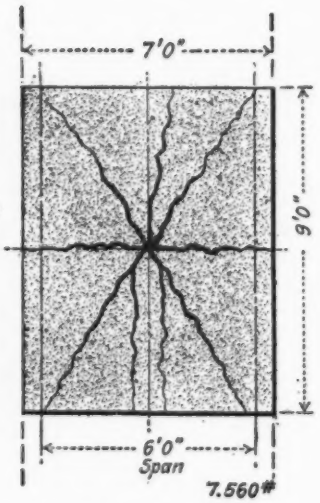
instructive and is indicative of the width over which the bending moment was most largely resisted at failure. Perhaps it is significant that in the case of Nos. 706, 730 and 737, the



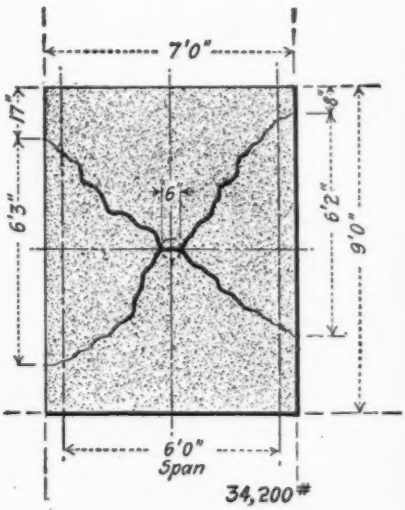
SLAB NO. 706.



SLAB NO. 730.



SLAB NO. 736.



SLAB NO. 737.

FIG. 10.—Bottom of Slabs after Failure, showing Shape of Cracks.

widths over which the cracks extend correspond reasonably well with the calculated effective widths under working loads.

No definite conclusions can be safely drawn from the tests thus far made, but the data collected are useful in indicating that in slabs of the kind described and of 3 to 6-ft. span length, the concentrated central load might quite safely be considered as carried by a width of slab equal to not more than 0.8 of the span length. Detailed conclusions are not warranted until more tests are made. The specimens, on account of their size, are heavy and unwieldy; their testing is very laborious and consumes time; and it is therefore earnestly hoped that the solution of the problem will be hastened by the cooperation of other investigators in this field.

In conclusion the writer wishes to acknowledge his appreciation for the cooperation and suggestions of Mr. Charles H. Moorefield in designing these tests and preparing this paper, to Messrs. F. H. Jackson, Jr., and J. P. Nash for their assistance in making the tests, and to all others who have lent their aid in obtaining the above-described results.

DISCUSSION.

Mr. Slater.

MR. W. A. SLATER (*by letter*).—An investigation similar to the one reported on in Mr. Goldbeck's paper is being carried on at the University of Illinois. Three series of tests have been completed, and some of the results were reported in a paper presented by the writer at the Ninth Annual Convention of the National Association of Cement Users in December, 1912. In so far as these tests may at present be considered to give basis for conclusions, these conclusions agree closely in kind with

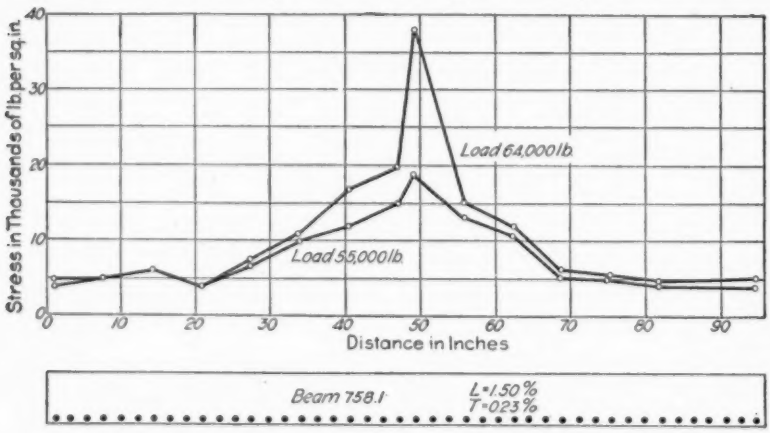


FIG. 1.

those reached by Mr. Goldbeck, though there are some quantitative variations from his results.

The tests on which this discussion is based were made on (*a*) a large number of beams having a span of 4 ft. and widths varying from one-half the span up to twice the span, (*b*) one beam having a span of 10 ft. and a width half as great, and (*c*) two beams having a span of 30 in. and a width 3.2 times as great. The loads were applied at the one-third points of the span.

Mr. Goldbeck has stated that his deformation measurements were taken generally upon the concrete, and that measurements upon the steel give such erratic results as to be of little

value. The writer agrees that measurements on steel are likely to be erratic, but he believes that since the steel stress is more likely to be critical than the concrete stress, conclusions should be based on the results of measurement of steel stress. This seems especially important in view of the form of typical steel stress distribution curves shown in Fig. 1.[1] Here it appears that the variation between the stress at the center of the beam and that at the edge is much more extreme than is found in the concrete stress. The effective width then (that width in which, if the entire moment were resisted, a uniform stress would be developed which would be equal to that actually found at the center of the beam) should be less than that as determined on **Mr. Slater.**

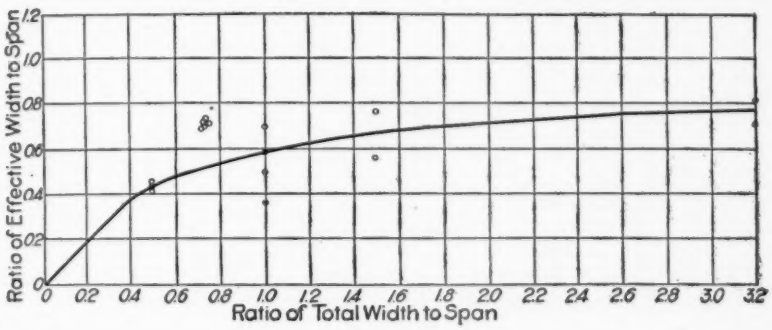


FIG. 2.

the basis of concrete stresses, and deductions as to relation between span and effective width will be more conservative. In one portion of Mr. Goldbeck's paper it is stated that cast-iron plugs drilled for measurement were wired to the reinforcing. Wherever a crack opens there must be local slipping of the bar through the concrete, and since these cast-iron plugs must move with the concrete rather than with the steel any movement of the plugs will indicate essentially the opening of cracks rather than stress in the steel. If, then, measurements for steel deformation were taken on these plugs the results should be expected to be erratic. More consistent results have been obtained from measurement directly upon the steel.

Fig. 2 shows the ratio of the effective width to the span as

[1]Acknowledgment is made to the *Engineering Record* for the use of the cuts of Figs. 1 to 3 of this discussion.—ED.

Mr. Slater. determined from the measured steel stresses in the University of Illinois tests. It is to be noted that there is apparently a sudden change in the distributing action between the points where the width is respectively three-fourths of and equal to the span. The curve was made to conform to the lower value. Apparently at a width of about two spans this ratio becomes constant, or nearly so, and equal to about seven-tenths of the span for the mean curve. The fact that Mr. Goldbeck's values of the ratio of effective width to span are higher than those found by the writer may be due partly to the fact that they are

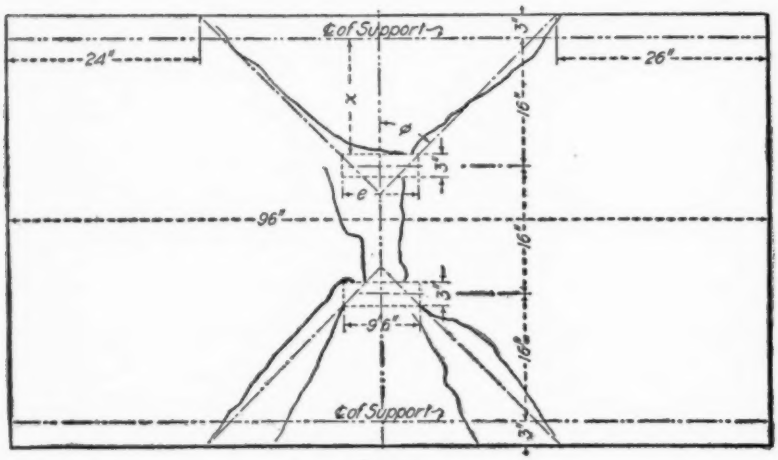


FIG. 3.

based on concrete stress instead of steel stress, and partly to the fact that the load in his tests was applied at the one-third points of the span.

That the method of loading may be expected to influence the effective width may be seen by comparison of Fig. 3 of this discussion with Fig. 9 of Mr. Goldbeck's paper. It has been pointed out that the distance between the radiating cracks where they reach the edge of the beam is to some extent indicative of the effective width, and it has been suggested that for a very wide beam this distance is about equal to the span. In other words, the angle ϕ between the center line of the beam and the general direction of the crack is constant and its tangent

equal to unity. If the distance from the load to the support be called x, the effective width b, the span s, and the width of loading blocks e, then **Mr. Slater.**

$$b = 2x.tan\phi + e = 2x + e.$$

$$\text{If } x = \frac{s}{2},\ b = s + e.$$

$$\text{If } x = \frac{s}{3},\ b = \frac{2}{3}s + e.$$

The former value agrees approximately with Mr. Goldbeck's results and the latter with those obtained by the writer. If as a conservative coefficient $tan\phi$ be taken as 0.8, as is proposed by

TABLE I.

Beam No.	Width, in.	Longitudinal Reinforcement, per cent.	Load Considered, lb.	Measured Stress, lb. per sq. in.		Calculated Stress, lb. per sq. in.	
				Maximum.	Average.	Based on Effective Width.	Based on Total Width.
765.1	72	1.04	32 000	20 000	10 300	21 500	11 100
765.2	72	1.04	40 500	29 000	11 000	37 000	14 100
753.1	48	1.51	42 500	21 000	12 300	27 000	15 900
753.2	48	1.51	42 000	22 500	15 600	22 500	15 600
763.1	48	1.04	31 600	42 000	15 600	46 000	16 500
763.2	48	1.09	40 300	42 000	21 400	40 000	20 200
762.1	36	1.02	38 500	26 500	25 300	28 300	27 300
751.1	24	1.07	37 000	35 000	29 600	44 500	37 700
752.1	24	1.07	41 500	37 000	33 600	32 000	29 800

Mr. Goldbeck, $b = 0.8s + e$ and $b = 0.53s + e$, for beams loaded at the center and one-third points respectively.

Table I has been prepared to show a comparison between the measured and the calculated stresses. It is seen that when the width assumed in the calculation is the total width of beam, the calculated stress agrees reasonably well with the average measured stress. When the width assumed is the effective width, the calculated stress corresponds with the maximum measured stress. Thus, if the effective width at any load be known, a beam may be designed so that the maximum stress will be approximately equal to any stress which may be assumed in design. However, it must be borne in mind that the determination of the effective width has been based on the stresses

Mr. Slater. observed at loads less than the ultimate. While it may be expected that in a beam designed by the methods outlined here, the stress in the center of the beam at the design load will not be larger than the assumed working stress, the factor of safety may be less than that which is indicated by the ratio of the yield point stress to the working stress assumed. If from the maximum loads given in Table III of Mr. Goldbeck's paper, the bending moment be calculated and equated to the expression for resisting moment, as given in the equation $M = pf_s jbd^2$, it is possible to solve for b, the width of beam which must be effective to produce the yield point steel stress of 38,800 lb. per sq. in., the yield point of the reinforcement rods used in Mr. Goldbeck's tests. These calculations give values of the effective width sometimes higher and sometimes lower than obtained by the method employed in Table II of his paper. In the tests made at the University of Illinois, it seems in general that the effective width as based on the ultimate load is less than that obtained on the basis of steel stress at loads less than the ultimate. The meaning of this may be either that the steel stress increases faster proportionally than does the load, or that the failure is due to something other than stress in the steel—perhaps to transverse tension in the concrete. An attempt has been made to fix a criterion to determine whether transverse tension in the concrete is likely to be the determining factor in any given case, but so far nothing general has been determined. In view of the uncertainty which surrounds the matter as yet, it seems to the writer that it would be in the interest of safety to use a value of $\frac{2}{3}$ for $tan\ \phi$ or an effective width of $4/3\,x+e$ and to limit the longitudinal reinforcement to one per cent or less. In view of the statement which follows, indicating that the effective width is independent of the amount of longitudinal reinforcement, it may appear inconsistent to limit the latter to one per cent. This limitation is placed because of the possibility that in a beam with a large amount of longitudinal reinforcement and a relatively small depth, failure may be caused by transverse tension in the concrete and not by longitudinal steel stress. Under such circumstances, the effective width would not be a significant factor in the calculation of the ultimate strength of the beam.

Mr. Slater.

It must be understood that the equation proposed for determining the effective width represents the conditions which may be reached in the limiting case when the span is finite and the width infinite. For widths greater than $2s$ it probably is a sufficiently close approximation to be used without fear of serious error. For a beam whose width is less than twice the span, the proportionate reduction in the effective width is indicated in Fig. 2.

In Mr. Goldbeck's paper it is mentioned that "factors other than span length, such as depth, percentage of reinforcement, etc., may have influence on the effective width." Experimental evidence has been found indicating that for loads below the ultimate, the effective width is independent of the percentage of longitudinal reinforcement. By analogy, it would be expected to be independent of depth also. In Table II of Mr. Goldbeck's paper, however, a slight tendency for the effective width to increase with the depth is apparent. On the other hand, tests at the University of Illinois indicate a slight tendency for the effective width to vary inversely with the depth. In view of the fact that the variation in effective width corresponding with variation in depth is very slight, and in opposite directions in the two cases, it would seem that depth as a factor influencing the effective width is unimportant. Thus it is indicated that while factors other than span length may have influence on the effective width, these other factors are relatively unimportant. Therefore, for beams without transverse reinforcement the method observed in the paper and in this discussion, of considering the span length as the important factor governing effective width, seems to be justified.

In the oral presentation of his paper, Mr. Goldbeck has called attention to the fact that assuming the effective width as a constant proportion of the span results in the obtaining of a constant depth for all beams required to support the same concentrated load P regardless of the span. This does not seem unreasonable when it is remembered that for the same total load similarly placed on the span, the moment and the effective width both increase directly with the span, thus keeping the moment per unit of width constant. This is shown by the following equations:

Mr. Slater.

Let S_1 = span, b_1 = effective width, and M_1 = moment on span S_1;

then $\frac{M_1}{b_1}$ = moment per unit of width.

For any other span kS_1, kM_1 = moment and kb_1 = effective width.

The moment per unit of width then becomes $\frac{kM_1}{kb_1} = \frac{M_1}{b_1}$ as before.

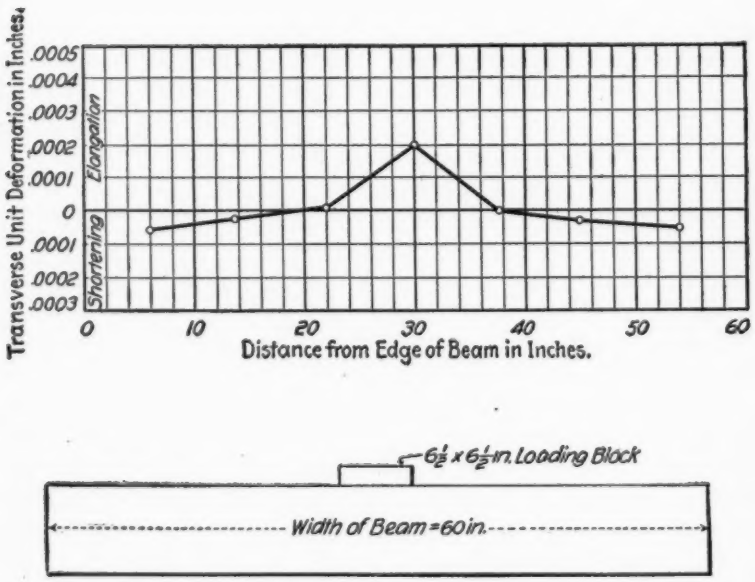


FIG. 4.

The moment considered here, of course, is only the live-load moment. The dead-load moment shows a substantial increase with the span, and the corresponding increase in depth of slab or percentage of reinforcement required is considerable.

In this discussion all that has been said applies only to beams without transverse reinforcement. Tests have been made on beams having various percentages of transverse reinforcement, and in so far as deductions are justified, these tests have not shown conclusively that transverse reinforcement for the

purpose of resisting transverse bending stress is economical. As a general consideration, however, it seems that there ought to be a small amount of transverse reinforcement for the purpose of distributing deformation due to variations in temperature. **Mr. Slater.**

In some of the University of Illinois tests, measurements of deformation in a transverse direction at several points along the width of the beam were taken at the center of the span. Results of such measurements are shown in Fig. 4. It should be expected that transverse flexure would be present in a beam loaded as this one was, and the shape of this curve is such as to confirm this opinion. However, one feature of this curve which may be unexpected is that the transverse deformation changes from a shortening at the center of the width of the beam to an elongation near the edge. I should like here to ask Mr. Goldbeck if he found any indication of this phenomenon, namely, elongation in a transverse direction on the upper surface of the slab.

MR. A. T. GOLDBECK.—The deformation readings taken on the top of the slab parallel to the supports were very small and in general indicated compressive stresses not exceeding 40 to 50 lb. per sq. in. In a few instances, tensile stresses of negligible magnitude were detected, but these might have been caused by inaccuracy in reading the strain gage. **Mr. Goldbeck**

MR. SLATER.—When results of this sort were first obtained at the University of Illinois a year ago they were regarded with much suspicion. However, the values plotted in Fig. 4 are from a subsequent series of tests and are obtained from averages of a number of independent observations. The values obtained from individual observations, not given in Fig. 4, were sufficiently concordant and the curve shown is sufficiently symmetrical to give one considerable confidence in the results. **Mr. Slater.**

MR. W. K. HATT.—A somewhat similar problem arises in the ordinary flat-slab reinforced concrete floor in which a comparatively wide band or beam element rests on a narrow column support. I should like to ask the author of the paper if he observed the fine cracks which occur at comparatively low steel stresses of 4000 to 5000 lb. per sq. in. **Mr. Hatt.**

MR. GOLDBECK.—I might say that the readings of the strain gage taken on the bottom of the slabs were always indicative of the position of the cracks. Whenever we obtained a **Mr. Goldbeck.**

Mr. Goldbeck. large reading in tension, we always looked for a crack and invariably discovered it. Moreover, the cracks were always discovered under low tensile stress.

Mr. Marston. MR. A. MARSTON.—In our bridge designing in connection with highway work, we find this problem to be of the greatest importance, and as a suggestion for further work, I should like also to call attention to the connected problem of finding the distribution of loads from a concentrated load applied through a depth of filling material. A similar problem also arises in the design of the ordinary bridge floor consisting of plank resting on wooden or steel joists; in fact, it seems to be continually coming up in our highway bridge design work.

Mr. Slater. MR. SLATER.—In the table given by Mr. Goldbeck, there is a slight increase in the effective width as the depth increases, that is, a variation of from about nine-tenths of the span for a depth of 4 in. up to 1.2 times the span for a depth of 6 in.

Again, there were one or two other variables in these tests, and I wonder if variation in the effective width is to be attributed to the depth or if it is more likely to be accidental. At the University of Illinois, we have tested beams having depths of 3 and 6 in. without any intermediate depth, and though there are not much data on that point, the tendency seems to be to decrease the effective width with the increase of depth. This tendency is very slight and in a direction opposite to that shown by Mr. Goldbeck's tests. On the same basis that percentage of longitudinal reinforcement may be neglected as a factor, the ratio of depth to span or to width also may be neglected. I should like to ask whether Mr. Goldbeck has an opinion on this point.

Mr. Goldbeck. MR. GOLDBECK.—I believe we have obtained so few results that an opinion is hardly warranted. I don't think we have made enough tests to determine whether the effective width is dependent on the depth of the slab or whether it is not. I think we shall require a great many more tests to determine all the factors that enter into this problem.

Mr. Morris. MR. C. T. MORRIS (*by letter*).—Practically all loads applied to highway bridge floors are concentrated loads on small areas. The present methods of treating these concentrated loads in designing reinforced concrete slab floors and in designing the supporting beams beneath, are so widely at variance and the

methods of analysis so unsatisfactory, that the writer, as Engineer of Bridges for the State Highway Department of Ohio, started a series of tests in the fall of 1911 to determine the distribution of concentrated loads through reinforced concrete slab floors. These tests have been carried on in the concrete laboratory of the Ohio State University. The set of tests contemplated involves three distinct series: **Mr. Morris.**

1. The determination by laboratory experiments of the distribution of the load through the slab to the supporting joists of a floor with several lines of joists.
2. The determination by laboratory experiments of the width of slab over which the concentrated load should be considered as distributed when designing the slab itself.
3. The determination of each of the above distributions by experiments on actual bridge floors under service.

The first two series have been about half completed.

Of the first series eight slabs 5 by 8 ft. have been tested, supported upon three lines of joist of 12-ft. span, spaced $3\frac{1}{2}$ ft. center to center. These tests were made with a single concentrated load over the center of the middle joist. The tests were run only up to the safe load on the joists.

Of the second series 7 slabs have been tested to destruction. These were all of $3\frac{1}{2}$-ft. span, center to center of supporting beams, and were of three widths, one 1 ft., three $3\frac{1}{2}$ ft., and three 7 ft. Of this series there yet remain to be tested 14 slabs, of which 5 are made and ready for test and 9 yet remain to be made. Five of these nine are so large that at present they can not be handled in our laboratory, but the other four will probably be made this summer and tested in the fall.

It is expected that the third series of experiments, namely the tests of actual bridge floors, will be completed this summer.

The data are not yet sufficient to warrant any definite conclusions, but in general it may be stated from the first series, that the middle beam carries not over 50 per cent of the total load when the slab is 6 in. thick, $3\frac{1}{2}$ ft. span, and the joists are 12 ft. span. From the tests of the $3\frac{1}{2}$-ft.-span slabs of the second series it would seem that the effective width of slab was about equal to the span as given by Mr. Goldbeck in his paper.

TEST OF A 40-FOOT REINFORCED CONCRETE HIGHWAY BRIDGE.

By D. A. Abrams.

Preliminary.

Among the first endeavors of the Illinois Highway Commission, after its organization in 1906, was the improvement of the ordinary highway bridges of the State, and their engineer, Mr. A. N. Johnson, immediately inaugurated plans for the design and introduction of a type of bridge which would be satisfactory for a large number of short-span crossings. Every consideration indicated that reinforced concrete was the proper material. An exhaustive study of the different types, led to the design of a through-girder bridge with suspended floor. A bridge of this type has obvious advantages for roadways of ordinary width, and is peculiarly adapted to the conditions in Illinois, since it gives a maximum water-way in locations where headroom is limited. Several hundred bridges of this form have been built through the cooperation of the city or township road commissioners and the Highway Commission, and all are now giving satisfactory service. The spans thus far constructed vary in length from 24 to 60 ft.

In order to furnish an object lesson for the benefit of skeptical advocates of older types of highway bridges, it was determined to make a test on a bridge of this kind by subjecting it to a load much more severe than it would ever be expected to carry in service. It was also felt that in this way valuable information could be obtained as to the action of the bridge under unusual loading, and thus secure a check on certain details of the design. Accordingly, in 1907, a bridge of 40-ft. span and 18-ft. roadway was built for testing purposes, from the design that was then being used. The test bridge was built inside the prison yard at the Southern Illinois Penitentiary, near Chester. All labor of constructing and testing the bridge was performed by convicts.

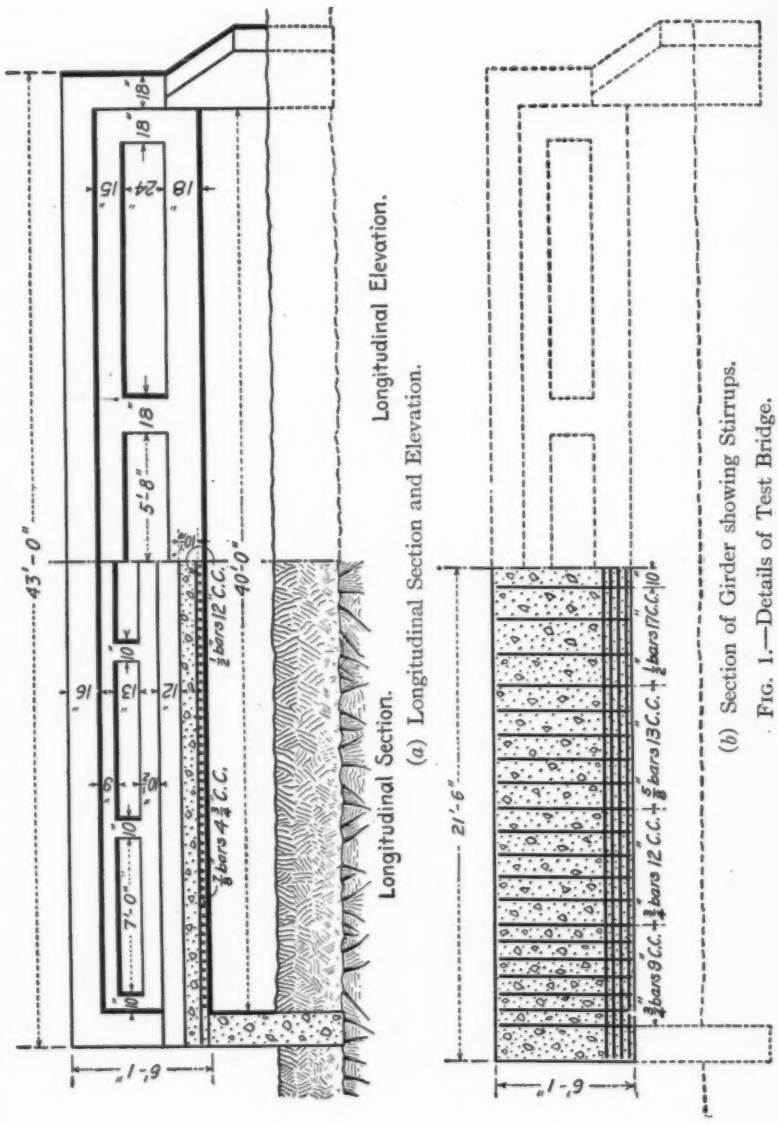
Mr. A. N. Johnson is responsible for this design and for planning and carrying out the tests described below; and the work of building the test bridge and conducting the tests was done under his direction. The writer is indebted to Mr. Johnson for information concerning the construction of the bridge.

Especial acknowledgment is due to the officials of the Southern Illinois Penitentiary for their hearty cooperation in this work. The expense of such a test would have been prohibitive under ordinary circumstances, and these experiments were possible only as a result of having the facilities of the penitentiary placed at the disposal of the Highway Commission. It was through the courtesy of Mr. L. L. Emerson, of the Mt. Vernon Car Co., that three carloads of pig iron were available as a portion of the loading material. Mr. N. E. Ensign, Instructor in the University of Illinois, gave valuable assistance in making the final load test and in compiling the data.

DESIGN AND CONSTRUCTION OF BRIDGE.

Design of Bridge.—The test bridge was designed for the usual loading of 125 lb. per sq. ft., uniform load, or a 24-ton traction-engine load distributed over an area 10 by 12 ft. The girders were 24 in. wide on top and had an over-all depth of 6 ft. 1 in. Ornamental paneling, both inside and outside, served to relieve the severe lines of the design. The floor consisted of a $12\frac{1}{2}$-in. reinforced concrete slab, suspended from the lower portion of the girders and built monolithic with them. The abutments were of the low wing-wall type of plain concrete, 18 in. thick. They rested directly on the rock floor of an abandoned quarry. Details of the design are shown in Figs. 1 and 2.

The longitudinal reinforcement of each girder consisted of ten $1\frac{1}{4}$-in. cold-twisted square bars, placed horizontally throughout their length in four layers, as shown in Fig. 1. The depth of the girders from the top to the centroid of the longitudinal steel (the effective depth) was 5 ft. 6 in. The webs of the girders were reinforced with vertical stirrups of $\frac{1}{2}$ to $\frac{3}{4}$-in. cold-twisted square bars, spaced as shown in Fig. 1(*b*). These stirrups were bent in a U-shape and they engaged all the longitudinal bars and extended to the top of the girder. The webs of the girders were further reinforced by carrying each third bar from the



(a) Longitudinal Section and Elevation.

(b) Section of Girder showing Stirrups.

FIG. 1.—Details of Test Bridge.

cross reinforcement in the floor up into the girder, as shown in Fig. 2. In the design, the girders were assumed to carry the entire dead and live load as simple reinforced concrete beams under a uniformly distributed load.

The bridge floor was suspended from the lower portion of the girders as indicated above and rested directly on the abutments at the ends of the bridge. The principal floor reinforcement consisted of $\frac{7}{8}$-in. cold-twisted square bars, $4\frac{3}{4}$ in. apart, placed across the roadway at right angles to the girders. The ends of these bars were disposed as shown in Fig. 2. One-half-inch twisted square bars, 12 in. apart, parallel to the girders,

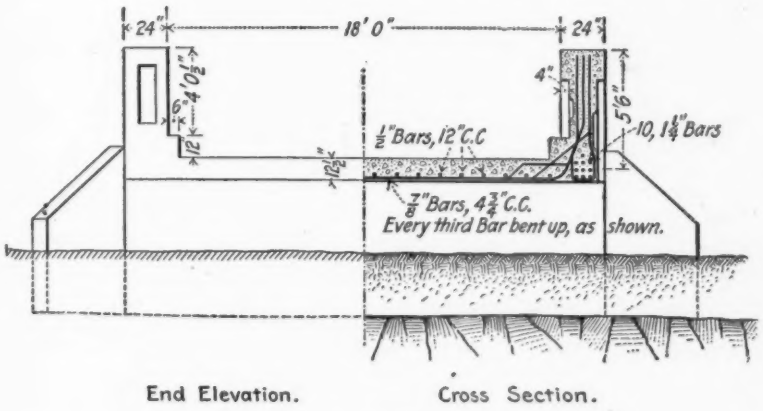


FIG. 2.—Section of Test Bridge.

served to distribute the floor loads and to take temperature stresses.

The bridge, exclusive of the abutments, contained 97 cu. yd. of concrete and weighed about 206 tons.

Construction of Bridge.—The concrete was a 1 : $2\frac{1}{2}$: 5 mix by loose volume. Mississippi River sand and a hard grade of crushed limestone from the prison crusher, in sizes varying from $\frac{3}{4}$ to $1\frac{1}{4}$ in., formed the aggregates. The concrete was mixed by hand. All reinforcement consisted of cold-twisted, mild-steel square bars. Bars could not readily be obtained in lengths of 43 ft. for the longitudinal girder reinforcement, hence it was necessary to weld all the $1\frac{1}{4}$-in. bars at about 10 ft. from one

end. The welds were alternated when the bars were placed. The welding was done at the prison shop. The results of tests made on samples of the original and welded bars as reported by the the laboratory of the Office of Public Roads, Washington, D. C., are given in Table I.

All labor of erecting forms, placing steel, mixing concrete, etc., was performed by convicts who had had no previous experience in this kind of work. It was extremely difficult to induce the men to do the amount of turning which was considered necessary for the best results, hence it is felt that the concrete

TABLE I.—TENSION TESTS OF TWISTED SQUARE BARS.

TESTS MADE BY OFFICE OF PUBLIC ROADS, WASHINGTON, D. C., FROM SAMPLES FURNISHED BY A. N. JOHNSON FROM MATERIALS USED IN TEST BRIDGE. REPORTED BY L. W. PAGE, JUNE 8, 1908.

Description of Bar.	Size, in.	Area, sq. in.	Elastic Limit, lb. per sq. in.	Ultimate Strength, lb. per sq. in.	Reduction of Area, per cent.	Remarks.
Solid.....	$1\frac{1}{4}$	1.49	56 000	68 000	46	Broke in grips.
Welded.....	$1\frac{1}{4}$	1.49	30 000	44 000	..	Broke in weld.
Solid.....	$\frac{7}{8}$	0.74	69 000	77 000	32	
Heated.....	$\frac{7}{8}$	0.74	47 000	61 000	62	
Solid.....	$\frac{5}{8}$	0.39	66 000	84 000	38	
Heated.....	$\frac{5}{8}$	0.39	38 000	62 000	63	

All specimens gave a silky fracture.

obtained was not of the best quality, even for the conditions under which the test bridge was built. The quality of the concrete in this bridge was apparently decidedly inferior to that obtained under ordinary field conditions.

The concrete was placed December 26 to 31, 1907. The temperature during construction varied from 54° to 28° F. On December 31, the temperature was as low as 28° during the forenoon, and stood at about 35° during the afternoon. The girders were sufficiently protected to show no frost action, but scale was formed over certain areas of the floor, which later peeled off to a depth of about $\frac{1}{4}$ in.

PRELIMINARY LOAD TESTS.

Two preliminary load tests were made. From May 5 to 10, 1908, when the bridge was about four months old, a load amounting to 106 tons, equivalent to 296 lb. per sq. ft., was placed on the bridge floor and was allowed to remain for three weeks. This load consisted of about 12 in. of crushed stone, upon which blocks of cut stone weighing 100 to 200 lb. each were piled. According to the constants used in the design, this load should produce a stress in the longitudinal steel of the girders of 16,000 lb. per sq. in.

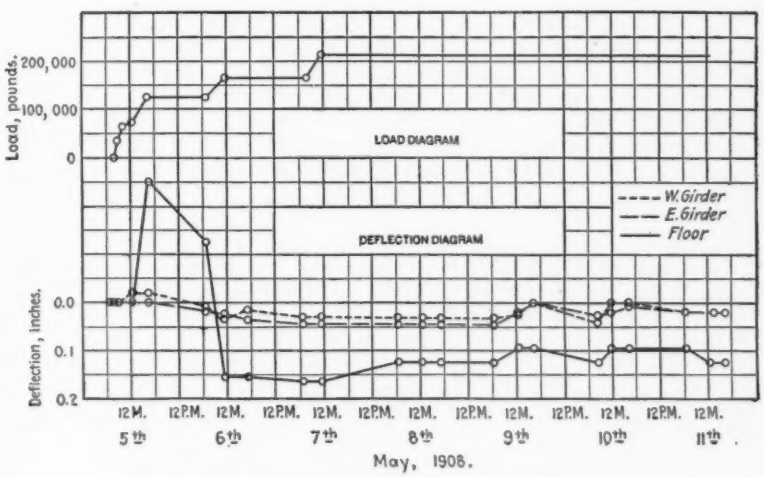


FIG. 3.—Deflections under Preliminary Test Load.

During the application of the load, and during the time the load remained in place, measurements were made of the deflections of the centers of the girders and the floor. In Fig. 3 the observed deflections and the progress of loading are shown. The curves show an average deflection of about 0.04 in. for the girders under a total load of 106 tons. The unknown effect of temperature, in connection with the rather crude methods of measuring deflections, will account for the variations found. The wide fluctuations in the deflection measured for the floor

during the early stages of the loading, cannot be accounted for; the readings during the later stages of the test are more consistent, and show a deflection of the floor, plus the girder, of about 0.12 in.

In June, 1909, when the bridge was $1\frac{1}{2}$ years old, a second preliminary load test was made under the direction of Prof. C. J. Tilden. In planning this test it was the intention to apply a heavy concentrated load, first to the bridge floor and then to the tops of the girders, in order to study the effect on the general behavior of the bridge, and in particular on the detail of the connection of the floor slab to the girders. The most practicable load available was a loaded freight car. A track was built and provision made for pulling the car on and off the bridge. The car was loaded with stone in such a way that a load of 44 tons came on one truck. The track was laid in 12 in. of ballast, but the load of 44 tons was the only load that affected the measurements taken in this test. In order to concentrate the load, a separate piece of track 5 ft. long was placed in the middle of the span to receive the loaded truck.

Deflections in the floor and girders and deformations in the girders were measured with the car on and off the bridge. The girder showed a center deflection of about 0.025 in. due to the load of 44 tons, but the temperature change with the load on or off the bridge was found to be about 0.02 in. The methods which were then available for measuring deformations in the girders, were not well adapted for out-door work in locations where wide variations in temperature and humidity are encountered. However, the test indicated that the deflection under load was small, and that temperature changes were a disturbing factor which would have to be taken into account in interpreting the results of such tests. The measurements of deformations were not very reliable, but they indicated a lower position of the neutral axis that had formerly been assumed. On account of the small deflections produced by the concentrated load on the floor, it was considered impracticable to attempt to apply a load to the girders only with the means available.

The writer is indebted to Mr. A. N. Johnson for information regarding the preliminary tests.

FINAL LOAD TEST.

Preparation.—Before beginning the final load test, loose material was cleared away and several brick piers were built under the girders and floor for use in measuring deflections at various points. The location of these piers is shown by the circles on the drawing in Fig. 4. Openings were cut in the concrete to the depth of the steel bars at various points along the lower flange of the girders, and in the floor in order to locate gage holes for use in measuring deformations in the steel. For

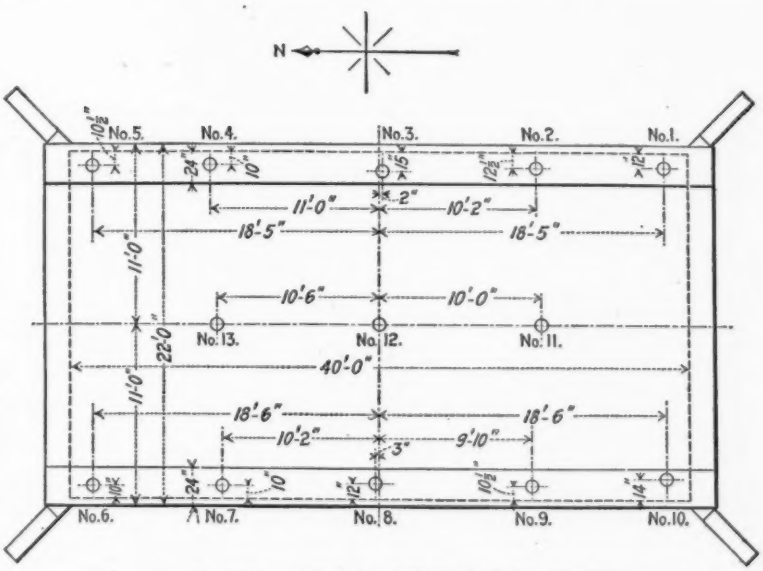


FIG. 4.—Location of Points of Deflection Measurements.

measuring concrete deformations at the upper surface of the girders, steel plugs were set in small holes drilled in the concrete. The outsides of the girders were white-washed in order to facilitate the mapping of cracks.

Method of Loading.—It was desired to apply the load in a manner that would approximate as nearly as possible the conditions of a uniformly distributed load on the bridge floor. The principal loading material consisted of crushed limestone from the prison crusher nearby. In order to prevent arching of the

loading material due to the deflection of the girders and floor, it was deemed advisable to build a series of separate bins for the crushed stone. The bins were eight in number, 7 ft. square inside, placed four on each side of the center line of the bridge, as shown in Fig. 5. They were built up of 2 by 6-in. lumber, laid flatwise and spiked together at the corners. It will be seen that the edges of the outer bins were $2\frac{1}{2}$ ft. inside the outer

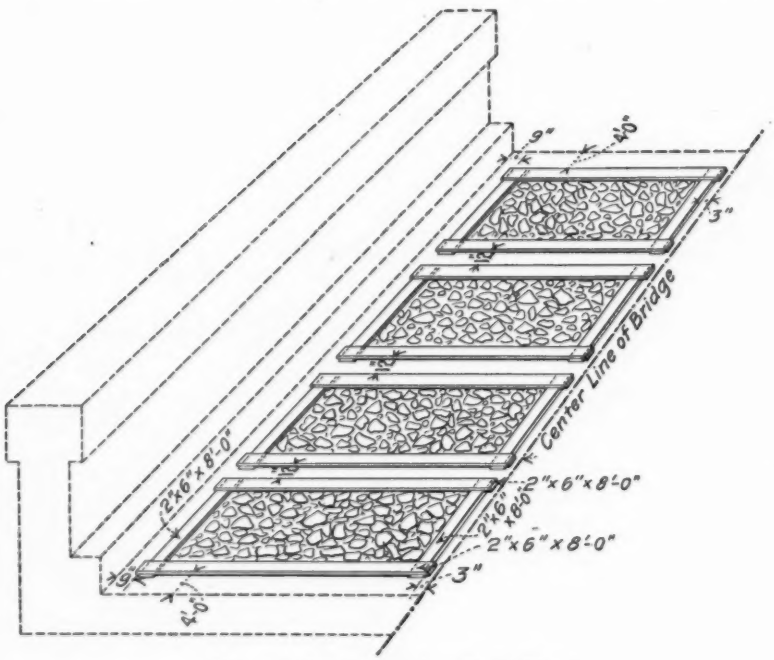


FIG. 5.—Arrangement of Stone Bins.

faces of the abutments. The bins were first built up to a height of about 5 ft. over the entire floor. A runway was then constructed over the tops of the bins and the crushed stone dumped from wheelbarrows. After this portion of the load had been placed, the bins were carried up a few feet at a time, and the remaining portion of the stone load was placed by means of a horse-power derrick, which was erected at the side of the bridge. Each wagonload of stone was weighed on a platform scale be-

TABLE II.—PROGRESS OF LOADING TEST BRIDGE.

Date.	Remarks.
July 26, 1911	Began building stone bins on bridge floor. Built brick piers for deflection measurements. Took series of temperature readings.
" 27	Continued building bins; took temperature readings, initial deflection readings, and initial readings of steel and concrete deformations.
" 28 to 30	Load of 6 tons on bridge, consisting of lumber in the stone bins. Took frequent series of temperature, deflection and deformation readings.
" 31	Began loading stone. Total load on bridge at 4.30 p. m., 89 tons.
August 1	Loading stone. Load at 4.30 p. m., 122 tons.
" 2	Built stone bins in forenoon. Load on bridge at noon, 128 tons. Began loading stone 2.30 p. m. Load at 4.30 p. m., 166 tons.
" 3	Began loading stone at 8 a. m. Load at 11 a. m., 219 tons. Built bins in afternoon; load at 5 p. m., 225 tons.
" 4	Began loading stone at 9 a. m. Load at 4.30 p. m., 280 tons.
" 5	Built bins; load at 4 p. m., 283 tons.
" 6 to 7	Load on bridge remained at 283 tons.
" 8	Began loading stone at 8 a. m. Load at 5 p. m., 335 tons.
" 9	Loading stone and building bins; load at 5 p. m., 369 tons.
" 10	Loading stone and building bins; load at 5 p. m., 418 tons.
" 11	Took full set of readings, plotted cracks and took photographs. Load remained at 418 tons.
" 12 to 25	Load, 418 tons. Took set of readings on August 25.
" 30	Began loading pig iron; 12 tons placed on each girder.
" 31	Loading pig iron on girders; at 2 p. m., 44 tons had been placed on each girder. No further load was put on east girder. Continued loading pig iron on west girder. At 4 p. m., 80 tons pig iron on west girder.
September 1	Loading pig iron on west girder. Load at 11.30 a. m., 100 tons. This was the maximum load applied to the test bridge—100 tons of pig iron on the west and 44 tons on the east girder, in addition to the 418 tons of stone on the bridge floor.
" 2 to 4	Load remained on the bridge as above.
" 5	Began removing pig-iron load.
" 6	All pig iron removed from the girders.
" 7	Took full set of observations under stone load of 418 tons.
September 8, 1911 to August 12, 1912	Load of 418 tons remained on bridge. Set of readings taken December 29, 1911.
August 12, 1912	Took set of readings under load of 418 tons.
" 13	Began unloading stone. Load at 4.30 p. m., 330 tons.
" 14	Unloading stone; load at 11 a. m., 274 tons. Load at 4.30 p. m., 205 tons.
" 15	Unloading stone; load at 11.30 a. m., 160 tons. Load at 5 p. m., 110 tons.
" 16	Unloading stone; load at 11 a. m., 100 tons. Load at 5 p. m., 70 tons.
" 17	Unloading stone; load at 3 p. m., 30 tons.
August 17 to September 3	Load remained as above.
September 3, 1912	Took deflection readings.
" 4	Remainder of load removed.
" 5	Took final observations.

fore it was dumped at the bridge site, so that at any time the exact weight of stone on the bridge could readily be determined.

The stone bins were finally filled to a height of 21 ft., which was about the maximum height to which it seemed feasible to build them; this was also about the limit to which the derrick could be worked. The total load on the bridge at this time was 418 tons. Later, about 144 tons of pig iron were placed on top of the girders without throwing any additional load on the floor.

Progress of Loading.—A detailed schedule of the loading and unloading is given in Table II.

Three or four days were spent in preparing the bridges for loading, and in making deflection and deformation measure-

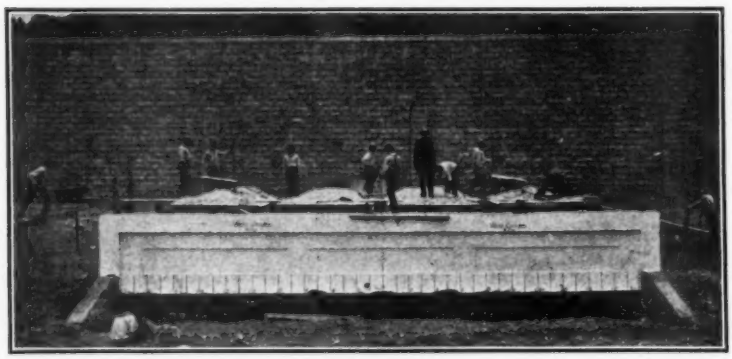
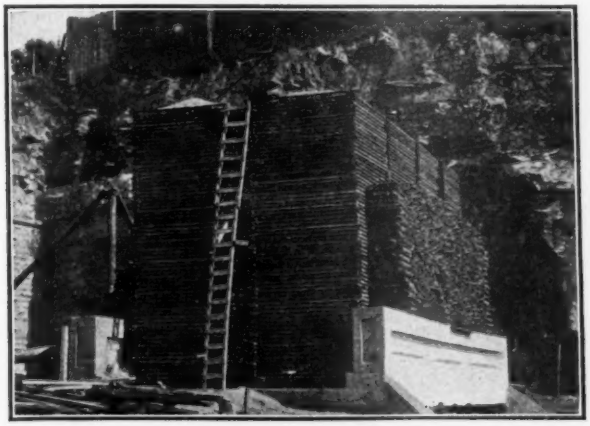


FIG. 6.—Test Bridge with Stone Load of 89 Tons.

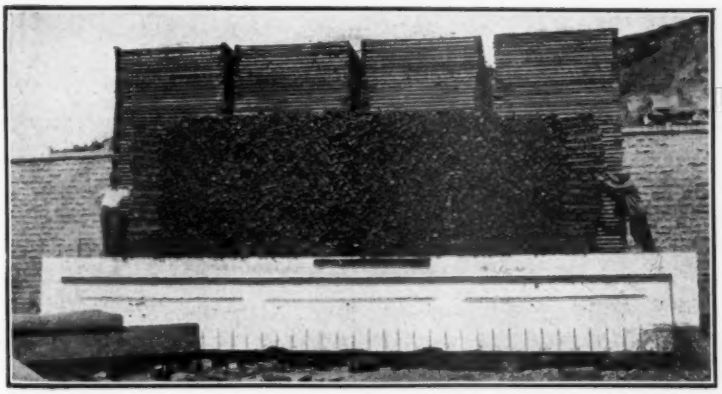
ments, in order to study the effect of diurnal temperature changes. Loading of stone was begun on July 31, 1911, and at the close of the day's work a load of 89 tons had been placed on the bridge. The appearance of the bridge at this time is shown in Fig. 6.

The observations of temperature, deflection of girders and floor, and the deformations of concrete and steel at the various points, were taken at frequent intervals during the period of applying the load, and while the load was in place. In general, a complete set of observations was taken at an early hour each day, before the morning had an appreciable effect, and another set after sunset. It was hoped that in this way the effect of the

direct sun heat on the bridge and the measuring instruments would be less troublesome. Observations of temperature and deflections were taken at more frequent intervals during the day.



(*a*) End View.



(*b*) Side View.

FIG. 7.—Bridge with Maximum Load in Place.

On August 10, 1911, a total stone load of 418 tons had been applied to the floor. The load remained unchanged until August 30, when the placing of pig iron on the tops of the

girders was begun. The pig-iron load was distributed over the middle 30 ft. of the 40-ft. span. At first a load of 44 tons was placed on each girder. It was then seen that the amount of pig iron available, if placed equally on both girders would not produce as high stresses as had been expected; therefore, all the remaining pig iron was placed on the west girder. On September 1, a load of 100 tons of pig iron had been placed on the west girder, and 44 tons on the east girder, in addition to the 418 tons stone load. The appearance of the bridge under full load is shown in Fig. 7. The distribution of the load on the west girder is approximately shown in Fig. 18.

It was the expectation that in this test the bridge would be loaded to failure, but the loading material available and the facilities at hand did not permit. The maximum load remained undisturbed from September 1 to 5, 1911. On September 6, the pig-iron load had been entirely removed, but the stone load of 418 tons was allowed to remain in place until August 13, 1912. One complete set of observations were taken on December 29, 1911. On August 13, 1912, the removal of the stone and bins was begun. Observations of the deformations in the concrete and steel of the girders and deflections of the girders were taken during the unloading of the stone, and after the removal of the load. Final observations were taken on September 5, 1912. It will be seen that the bridge carried an applied load equivalent to 318 tons per girder for four days, and a floor load of 418 tons for over a year.

Measurement of Deflections.—All measurements of deflection in the girders and floor were taken from the brick piers mentioned above. These piers were built with spread footings, and their tops extended to within about 8 in. of the lower surface of the bridge. Five piers were placed under each girder; one at the middle, one at each quarter-point, and one as close to each abutment as it could be built. Three additional piers were built along the center line of the floor. The deflection measurements were taken by means of an Ames gage attached to a screw micrometer, as shown in Fig. 8. The measurements were taken between two $\frac{1}{2}$-in. steel balls which were embedded in small steel plates. One such plate was set in plaster of Paris on top of the brick pier, and another attached directly above to

the underside of the bridge. The Ames gage had a travel of about ½ in. and could be read direct to 0.001 in. The screw micrometer, with a travel of 1 in., could be used for changes in deflection greater than the range of the Ames gage. As an illustration of the sensitiveness of this instrument in indicating changes of deflection, and also to show the action of the bridge, it may be of interest to note that with the full stone load on the bridge—418 tons, in addition to the weight of the bridge—an

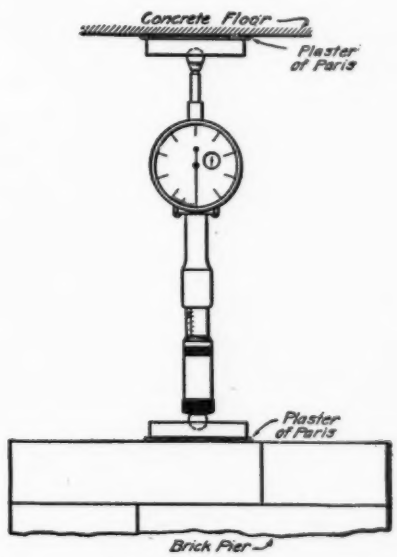


FIG. 8.—Deflection Instrument.

appreciable movement of the pointer of the deflection instrument was produced by a man walking along the top of one of the girders. With the west girder carrying a load of about 300 tons in addition to the dead load, an appreciable vibration of the pointer was produced by dropping the pieces of pig iron in place on top of the pile.

Temperature Observations.—In the preliminary tests mentioned above, the changes in the position of the girders due to temperature variations made the interpretation of the observa-

tions difficult, and showed the necessity of determining in advance the effect of temperature. In the final test, three thermometers were used and the readings recorded at frequent intervals. Thermometer A was placed at the middle pier under the center of the bridge floor, where it was shaded at all times, and indicated the atmospheric temperature. Thermometer B was placed inside the west girder about 10 ft. from the south end, in a steel pipe which had been set in the concrete for that purpose when the bridge was built. Thermometer C was placed with the bulb about 1 in. below the surface of the concrete in the top of the west girder, where it was sheltered from the direct rays of the sun by means of a light wood box which was open on one side to permit free circulation of air. During most of the time the hole in which thermometer C stood was filled with mercury. Three or four days before the application of load was begun, frequent observations of temperature and deflections were made for the purpose of determining the effect of the diurnal changes in temperature on the position of the bridge.

Measurement of Steel and Concrete Deformations.—Tensile deformations of the steel were measured at the mid-points of the girders and at points about 5 ft. each side of the middle, and at two points near the center of the bridge floor. The measurements at the center of the girders were taken on the three bars of the bottom layer, and the other girder measurements on the middle bar only. The deformations of the floor steel were measured on two $\frac{7}{8}$-in. bars about 12 in. apart, near the middle of the span. Deformations were also measured at points near the middle of two $\frac{3}{4}$-in. vertical stirrups, about 6 ft. from the north end of the west girder. Concrete deformations were measured at two points at the middle of the top of each of the girders and at single points about 5 ft. each side of the middle.

All deformation measurements were made by means of a modified form of the Berry strain gage. This instrument consists of a framework carrying a pair of conical points which made contact with small holes drilled in the steel bar, or in case of concrete deformations, with holes drilled in small steel plugs set in the concrete for that purpose. One of these points is

rigidly attached to the framework, while the other is movable, and is carried by a bent lever in such a way that the change in position of the movable point due to a change in the length of the gage line is registered by an Ames gage attached to the framework. The framework of the instrument used in this test was of aluminum. The form of the instrument is shown in Fig. 9. The gage length was 10 in. in all cases. For a more detailed discussion of this instrument and its use, reference may be made to Bulletin No. 64, of the University of Illinois Engineering Experiment Station, "Tests of Reinforced Concrete Buildings under Load," by Arthur N. Talbot and Willis A.

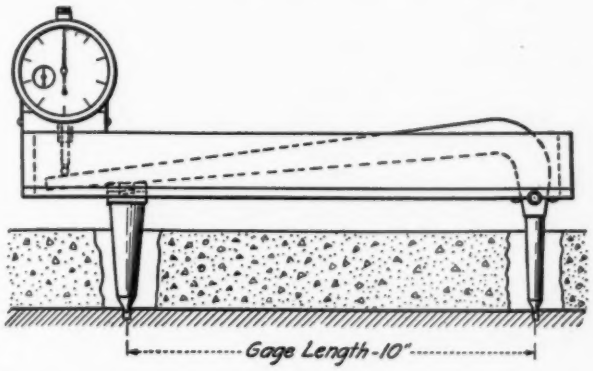


FIG. 9.—Extensometer Used in Measuring Deformations in Steel and Concrete.

Slater. The instruments used in this test were loaned by the University of Illinois.

RESULTS OF TEST.

Effect of Temperature on the Deflection of the Girders.—In Fig. 10, the relation of temperature to the position of the bridge is shown for the four days preceding the commencement of loading. The atmospheric temperature ranged from 67° to 83° F. The thermometer (C) on top of the west girder indicated the effect of heating the concrete. This effect is most noticeable during the afternoons after the girders have been exposed to the sun for a few hours. It is noteworthy that the west girder

showed more change in deflection than the east, but the east girder was protected from the sun by the prison wall until about the middle of the forenoon. The thermometer on top of the girder did not indicate the highest temperature to which the concrete was exposed, but it probably indicated the degree of heat which may be considered as effective in producing changes in the position of the girders. In one instance a thermometer placed in the sun on top of the girder registered 115° F., but

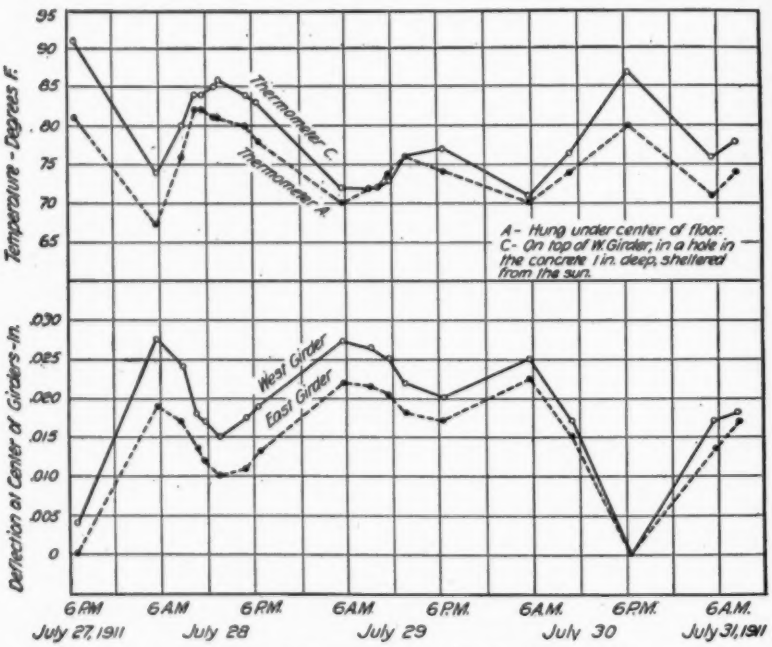


FIG. 10.—Effect of Temperature on Deflection of Girders.

other observations indicate that these high temperatures affect the concrete to a very small depth. On cloudy days the temperatures registered by the different thermometers were about the same.

The deflection of the girder is seen to vary directly with the change in temperature at the top of the girder, rather than with the atmospheric temperature. The maximum change in deflection due to this cause with the bridge unloaded was

0.027 in. The reason for the greater influence of the temperature change at the top of the girder is readily found in the fact that the concrete at this point is heated to a higher degree than elsewhere and the longitudinal expansion of the concrete due to this cause has the effect of lengthening the top chord of the girder, and, since the lower portion is not thus elongated, the girder must assume a curved form, and thus raise its center above its former position. As indicated on the diagram (Fig. 10), the change in deflection at the centers of the girders amounts to about 0.001 in. per degree.

These considerations indicate that in any set of observations in which careful measurements of deflection are taken on a structure of this kind, the results must be interpreted in conjunction with the temperature changes which are encountered. In subsequent figures in which the deflections of the girders have been plotted, no correction for temperature has been made, but the group of points which appears for each load shows the maximum variations due to temperature during the time covered by the measurements under the corresponding load. When a mean line is constructed, the error due to this cause is negligible.

It will be seen by reference to the load-deflection curves for the girders, in Fig. 11, that the change of deflection due to variations in temperature as indicated by the range of the points in the various groups is about the same, regardless of the load on the bridge. Under an applied load of nearly 300 tons on the west girder, there is as much change due to temperature as under dead load only.

Deflection of Girders under Load.—In Fig. 11, the center deflections for both girders have been plotted for the loading and unloading of the bridge. The approximate dates corresponding to some of the points are indicated in the figure. The action of the girders is quite similar to that which has been observed for reinforced concrete beams under load. Up to an applied load of 209 tons on each girder the curves have the characteristic parabolic form.

During the interval from August 10 to 30, 1911, with the load at 209 tons, the deflection changed from about 0.42 to 0.56 in. After the placing of the pig-iron load was begun on August 30, the change in deflection was comparatively slight

for the first portion of the load. Later, the curve follows a path which might have been predicted for it had the application of the load not been interrupted. During the four days which the

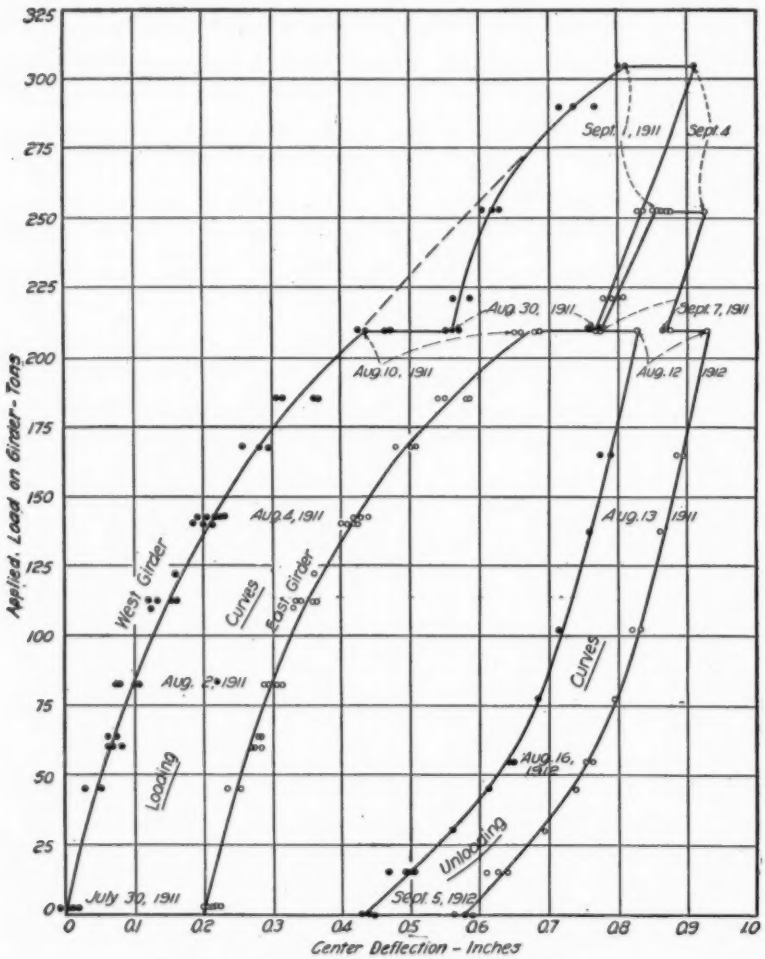


FIG. 11.—Load-Deflection Curves for Girders.

west girder remained under the full applied load of 309 tons, the center deflection changed from 0.81 to 0.91 in. No measurements of deflection were taken during the unloading of the

pig iron. After the removal of the pig iron the west girder deflection was about 0.30 in. greater than it was immediately after the stone load was applied. During the interval of about 11 months after the removal of the pig iron, with the stone load in place, the change in deflection of both girders was about the same as that which occurred during the 20 days following the placing of the stone load. This, however, is as might have been expected, since the bridge had been subjected to a much higher load in the meantime. After unloading, the girders showed a permanent deflection of about 0.45 in.

In Fig. 12 several curves have been drawn which show

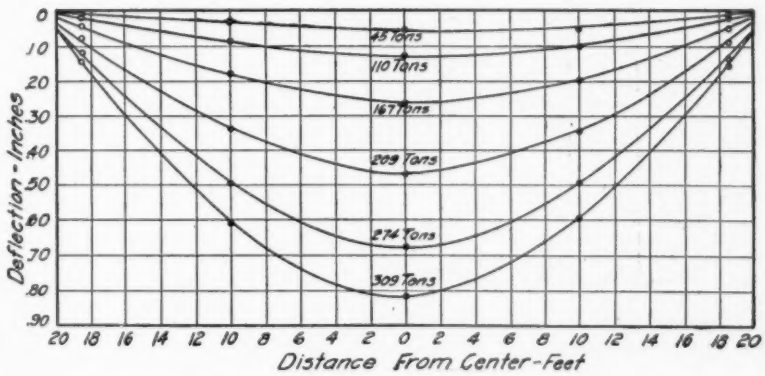


FIG. 12.—Elastic Curves for West Girder.

the deflection of the west girder at the various points where measurements were taken, for loads varying from 45 to 309 tons. These lines may be said to represent the elastic curves for the girder. The remarkable symmetry of the curves will be noted. By projecting the curves beyond the last observation points to the abutments, it is seen that there was a slight settlement of the ends of the girders as the load increased. This was probably the result of the concentration of the load at the outer face of the abutments due to the deflection and tilting of the girders. However, this is a small amount and no correction has been made for it in plotting the curves.

Deflection of Floor Slab under Load.—In Fig. 13 the deflections of the center of the floor slab have been plotted in terms of

the stone load, considered as uniformly distributed over the floor. The maximum load placed on the floor amounted to about 1450 lb. per sq. ft. The deflections given for the floor have been reduced in such a way that they represent the true deflection of the floor slab with reference to the girders and not the total depression of the floor at this point. The maximum

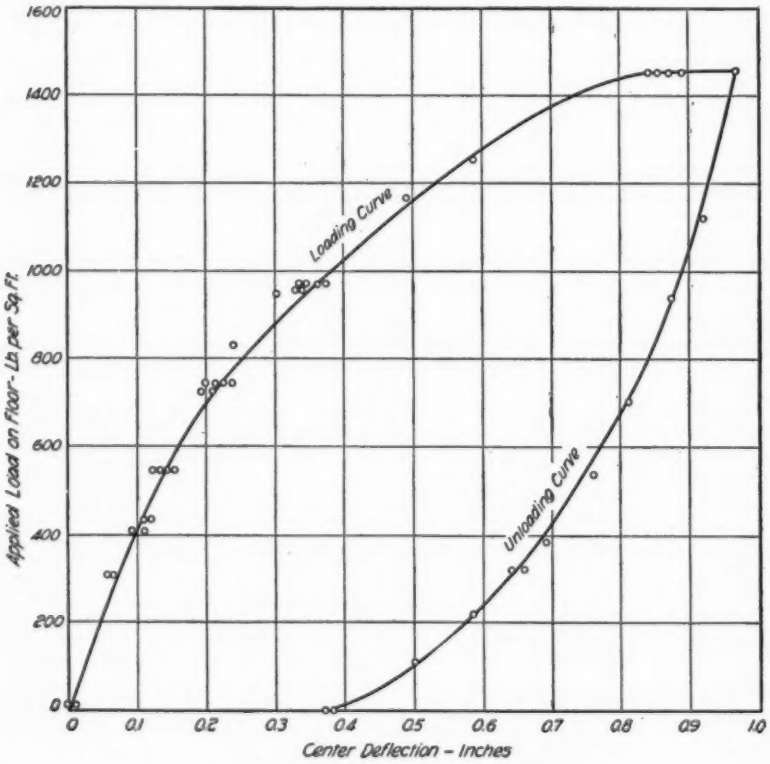


FIG. 13.—Load-Deflection Curves for Floor Slab.

deflection of the floor was about 0.96 in. Upon removal of the load, the floor slab showed a residual deflection of 0.37 in.

Effect of Temperature on Deformation Measurements.—It should be borne in mind that in attempting to make accurate measurements of deformations in the concrete and steel of a structure of this kind, the difficulties are greatly increased over

those encountered in the usual indoor laboratory test. Variations in temperature and other changes in weather conditions affect the structure as well as the instrument used, and under the very best conditions wide variations may be expected in observations of this kind. This is especially true of the concrete deformations which were taken on top of the girders, since the readings were affected by the local heating of the girders, and by the direct rays of the sun and the radiated heat on the instrument. It was found that the deformation measurements taken at hours when the direct rays of the sun fell upon the instrument were not very reliable.

The observations made before loading was begun did not cover a sufficient range to indicate the exact effect of temperature variations on the concrete and steel deformations. However, the range of the points for certain loads on the load-deformation diagrams for the girders show the extreme variations which were found.

There are so many variables which affect a measurement of this kind, that it is impossible in this case to differentiate between the errors due to instrument adjustment, the personal equation of the observer, and the actual variations in the deformations due to stress or temperature. If it were not true that some engineers entertain mistaken ideas on this point, it would be considered superfluous to say that the changes in the position of the girders in a bridge of this kind, and changes in deformation due to temperature, have no influence on the stresses developed in the concrete and steel, as long as the ends of the girders are not fixed. It should be emphasized that it is change in deformation that we are now dealing with and as long as changes in temperature affect the results, this does not necessarily mean change in stress. In fact, in some cases the change of deformation due to change of stress seems to have been entirely masked by the change of deformation due to temperature.

The deflection readings were not appreciably affected by changes in temperature, since the quantities dealt with were larger, and there was little chance for variation in the adjustment of the instrument.

Deformations in Girders.—In this discussion only the deformations taken at the centers of the girders will be considered.

Fig. 14 shows the unit deformations in the steel at the centers of both girders, plotted with respect to the applied load in tons on the girders. Approximate dates are shown on the figure. It will be noted that these load-deformation curves exhibit about the same characteristics as were described for the

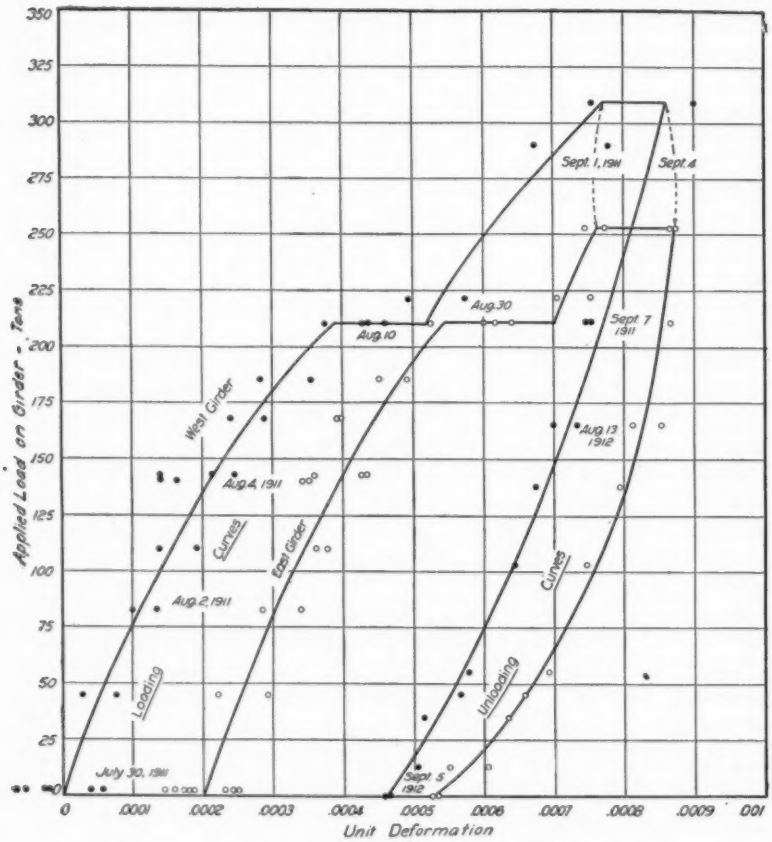


FIG. 14.—Load-Deformation Curves for Steel in Girders.

load-deflection curves. The observed stress in the steel at the center of the girder under an applied load of 102 tons per girder averaged about 11,700 lb. per sq. in. The deformations were measured on the lowest layer of bars, and they would be expected to represent the highest stresses developed in the

girder steel. Under the full applied load of 309 tons, the west girder showed a stress of 23,400 lb. per sq. in., which apparently was increased to about 25,500 lb. per sq. in. during the time this load remained in place. After the removal of the load, the west girder showed a residual stress of about 13,000 lb. per sq. in. It seems probable that if subsequent observations had been taken, this residual stress would have been found to be greatly

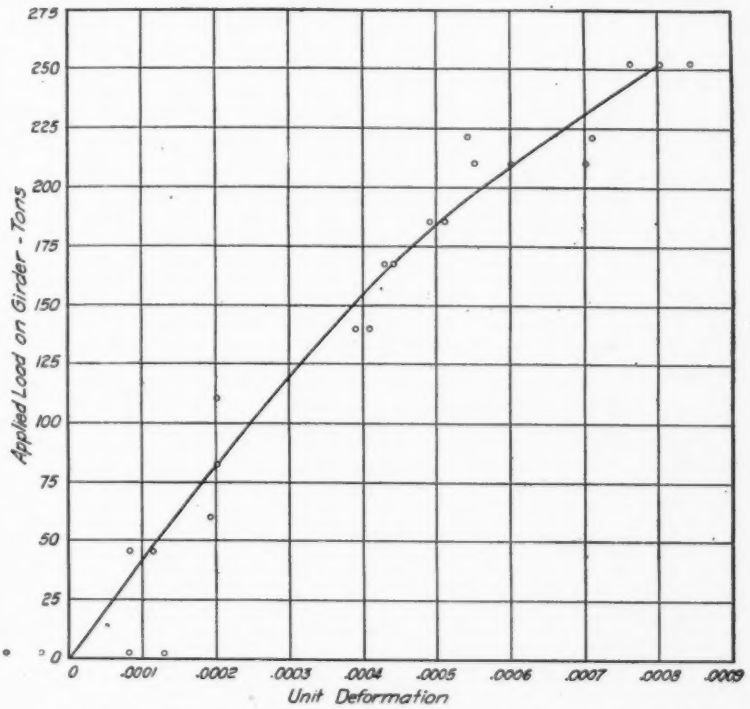


FIG. 15.—Load-Deformation Curve for Concrete at Top of Girder.

reduced after a period of rest. It will be seen that the observed points for steel deformation are somewhat scattered due to the causes discussed above, but it is believed that the curves drawn represent fairly accurately the results of the measurements. The action of the two girders was very similar, except that there was a difference in the applied load on the girders.

In Fig. 15 the deformations of the concrete at the top of the

west girder have been plotted. The curve is shown only to an applied load of 250 tons on the girder. The remaining readings were somewhat erratic on account of the rusting of the gage holes, and it seems best to omit them. The unit deformation for the maximum load derived from producing the curve is about 0.0011, which is probably 80 per cent of what might be expected for the ultimate deformation in concrete of this quality and age, and since this deformation in the concrete is due to applied load only, it represents a stress which must be near the ultimate compressive strength of the concrete.

Position of Neutral Axis.—Before making computations of stresses in any reinforced concrete member subjected to flexure, it is necessary to know the position of the neutral axis, or to

TABLE III.—NEUTRAL AXIS POSITION.

DETERMINED FROM MEASURED DEFORMATION IN THE GIRDERS.

Applied Load on Girder, tons.	Unit Deformation.		Neutral Axis Position.	
	Concrete at Top of Girder.	Steel at Bottom of Girder.	Distance below Top Surface of Girder, in.	Percentage of Effective Depth.
0	.....	.....	50[a]	76[a]
50	0.00012	0.000055	48	73
100	0.00025	0.00013	46	70
150	0.00039	0.00023	44	67
200	0.00056	0.00035	43	65
250	0.00080	0.00054	42	64
300	0.00104[a]	0.00074	41	62
309	0.00110[a]	0.00083	40	61

[a] Estimated.

make some assumption as to its location. It is evident that in a structure of such irregular section as the test bridge under consideration, the location of the neutral axis from theoretical considerations will be somewhat problematical, and that its position will vary widely with the assumptions made as to the properties of the concrete and the distribution of the stresses between the concrete and steel. The calculated depths of the neutral axis below the tops of the girders for various conditions are as follows:

Girder only, considered as a plain concrete beam..... 38 in.
Girder only, steel taking all tensile stress..... 26 in.
Girder only, both steel and concrete taking tension..... 31 in.
Bridge as a whole, both concrete and steel in floor and girders taking tensile stress..... 45 in.

In computing the above values, the modulus of elasticity of concrete was taken at 3,000,000 lb. per sq. in. However, a considerable variation in this modulus makes only a slight change in the computed depth of the neutral axis.

The deformations measured in the concrete at the tops of the girders and in the lower layer of girder bars give definite information as to the neutral axis position during the loading of the bridge. Table III shows the position of the neutral axis as determined from the deformations in the diagrams in Figs. 14 and 15, for applied loads on the west girder, varying from 50 to 300 tons. The values from Table III have been plotted in Fig. 16;

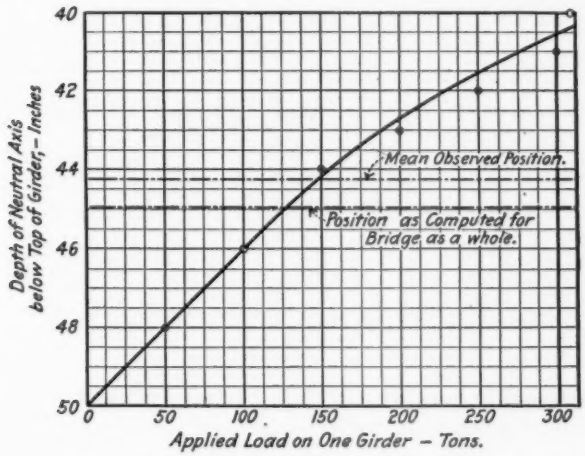


FIG. 16.—Observed Neutral-Axis Positions.

they indicate a steady rise of the neutral axis from about 50 in. under dead load only, to 40 in. under an applied load of 309 tons, with a mean value of about 44 in. It was seen above that a depth of 45 in. was computed for the condition that both concrete and steel in the entire section of girders and floor are considered as effective in taking the longitudinal tensile stress. The close agreement between the observed position and the computed position for the bridge as a whole indicates that the girders did not act as independent reinforced concrete beams in the manner usually assumed, but that the concrete in the girders and floor is effective in taking tensile stresses. The

gradual rise of the neutral axis as the load was increased is in accord with other tests of reinforced concrete beams. This rise is probably due to the opening of tensile cracks which extend up a short distance in the concrete, to a slight slipping of the bars in the concrete, and to the increasing deformation at the tops of the girders as the loading progressed. The positions of the neutral axis for the various conditions discussed above are shown with reference to the cross-section of the bridge in Fig. 17. In comparing the depth in inches with the percentages of the effective depth, it should be remembered that the steel deformations were measured on the lowest layer of bars—about 70 in. below the top—while the effective depth of the girder was 66 in.

Computed Stresses in Girders.—The maximum loads applied

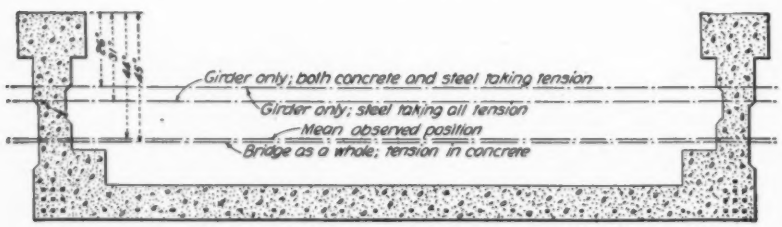


FIG. 17.—Section of Bridge showing Neutral-Axis Positions.

to one girder (west) were distributed approximately as shown in Fig. 18. The pig-iron load was distributed over a length of 30 ft.; the stone load over a length of 35 ft. For purposes of computation, the load will be considered as uniformly distributed over the full span of 40 ft. This gives a bending moment about 12 per cent less than that resulting from taking the loads as they are shown, but this error is offset by the consideration that a portion of the stone load on the floor was carried directly to the abutments without producing any stress in the girders.

The bending moment in one girder due to the maximum test load, considering the girder as a simple beam uniformly loaded, is

$$M_B = \frac{618{,}000 \times 40 \times 12}{8} = 37{,}100{,}000 \text{ in-lb.}$$

The resisting moment of the girder, considering the steel to take all tensile stresses, is

$$M_R = A f_s d'.$$

Equating bending moment to resisting moment,

$$f_s = \frac{M_B}{Ad'}$$

where A = area of longitudinal steel in girders, 15.5 sq. in.,
f_s = computed tensile stress in steel, and
d' = arm of resisting moment.

Taking the depth of the neutral axis at 40 in., as found for the maximum load from the deformation measurements (see Table III), the centroid of the compressive stresses is found to be 15 in. below the top of the girder, or at about what we may

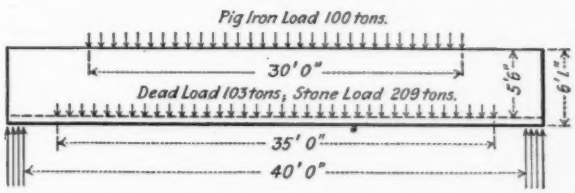


FIG. 18.—Approximate Distribution of Load on West Girder.

term the lower edge of the coping. This gives $d' = 51$ in. Substituting these values, and solving for the stress in the steel, $f_s = 47{,}000$ lb. per sq. in., if we consider all tensile stress taken by the steel of the girders. If the dead load on the girders is included, the computed steel stress becomes about 62,000 lb. per sq. in.

The maximum steel stress determined from the deformation measurements was 25,500 lb. per sq. in., which means that the measured stress in the steel accounts for only $\frac{25}{47}$ of the total tensile stress resulting from the applied load on the bridge. If the deformation measurements are to be depended upon, $\frac{22}{47}$ of the total tensile stress must be carried by the steel in the floor and by the concrete in the floor and girders. If we consider the longitudinal floor steel as carrying its part of the stress in the same way as the girder steel, the average computed steel stress is reduced to about 40,000 lb. per sq. in., which indicates that

about 36 per cent of the total tensile stress must be carried by the concrete of the floor and girders. Taking the moment of inertia of the entire concrete section about the neutral axis as determined from the deformation measurements,—40 in. below the top of the girders,—and making the necessary computations, we find that a maximum tensile stress in the concrete at the lower surface of the bridge of about 300 lb. per sq. in. will be sufficient to account for all tensile stress not taken by the steel. This assumes, of course, that the steel is taking all dead load stress, which is probably true, since at the time the centers were struck, the tensile strength of the concrete was comparatively low, and the concrete had ample time during the subsequent period of hardening to thoroughly adjust itself and come to an unstressed condition before the application of the final load. It is probable that concrete of this age would carry a tensile stress much higher than 300 lb. per sq. in. without failure.

The computed compressive stress in the girder from live load only is about 2200 lb. per sq. in., on the assumption that the bridge as a whole takes the stress, with the neutral axis at a depth of 40 in. For combined dead and applied load, this stress amounts to about 3000 lb. per sq. in. The maximum measured unit deformation in the concrete at a load of 250 tons on the girder was about 0.0008, which indicates a deformation of about 0.0011 at the maximum load of 309 tons. Assuming an initial modulus of elasticity of 3,000,000 lb. per sq. in. for the concrete, this deformation under maximum applied load only indicates a compressive stress of about 2000 lb. per sq. in. It may not be expected that the computed and the measured stresses in the concrete will show a close agreement, since the concrete deformation measurements were less satisfactory than those for the steel, and the strength and elastic properties of the concrete are uncertain.

It is recognized that there are discrepancies in the above analysis of the distribution of tensile stresses, for it would be difficult to account for the resulting deformations in the steel and the adjacent concrete if the stresses were distributed as indicated. However, the low position of the neutral axis, the low stresses measured in the girder steel, the minuteness of the tensile cracks in the girders, the rigidity of the connection of the

floor to the girders, and the general behavior of the bridge under these unusual loads, will admit of no other explanation.

Stresses in the Vertical Stirrups.—Vertical stirrups were provided to take the shearing stresses developed in the girders. Deformations were measured on two $\frac{3}{4}$-in. stirrup bars at about

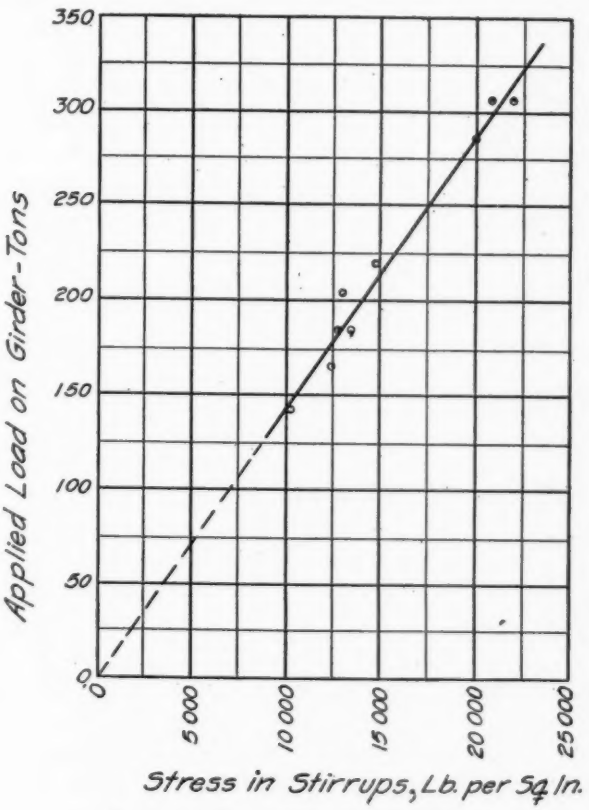


FIG. 19.—Stress in Vertical Stirrups.

6 ft. from the north end of the west girder. These measurements were not begun until a load of 140 tons had been placed on the girder. From this point to the maximum load the measured deformations indicate an increase in stress of about 12,000 lb. per sq. in. The stresses from the observed deformations in the girder bars have been plotted in Fig. 19.

If we consider the stress to increase uniformly as indicated by the observed points, the tensile stress in the bars may be said to increase from about 10,000 to 22,000 lb. per sq. in. during the time covered by the measurements. The size of the cracks in the girder at this point was not incompatible with such stresses. The close spacing of the diagonal cracks in this girder indicated that the web stresses were well distributed, and that the stress in the vertical stirrups was not high.

Deformation and Stress in the Floor Reinforcement.—Measurements were taken at the middle of two $\frac{7}{8}$-in. floor bars near the middle of the floor span. These measurements were subject to much less variation than was found in the girders, probably due to more constant temperature at this point. The values have been plotted in Fig. 20. The curve exhibits the usual characteristics for steel deformations in reinforced concrete beams. At the time of the application of the full stone load on the floor, these bars showed a measured stress of about 36,000 lb. per sq. in., which was increased to about 40,000 lb. per sq. in. before the stone load was removed. It was not practicable to make observations on these bars during the removal of the stone load. It was impossible to take deformation measurements in the concrete of the floor.

In computing the stresses in the floor-slab reinforcement, it was considered that the load was carried laterally by the system of $\frac{7}{8}$-in. twisted square bars, $4\frac{3}{4}$ in. apart, to the lower flanges of the girders. For purposes of comparing the computed stress in the reinforcing bars with the stresses found from the observed deformation at the middle of the floor slab, it is sufficiently accurate to consider that the entire stone load of 418 tons was uniformly distributed over the area covered by the bins. It is appreciated that a portion of this load near the ends of the bridge was carried directly to the abutments by the floor slab and did not produce stress in either the main system of floor reinforcement or the girders, but since we are concerned only with what occurs at the middle of the bridge span, it is clear that the above method is proper. For the full applied load of 418 tons this gives a uniformly distributed load of 1450 lb. per sq. ft. on the floor.

If we consider that the floor slab carried its load as a par-

tially fixed beam, it will be of interest to determine the elements of a beam which would develop the same stress in the reinforcing steel as that measured in the floor steel in the test. Using a uniformly distributed load of 1450 lb. per sq. ft., and an effective depth of 10.7 in., we find that a simple beam of 15.5-ft.

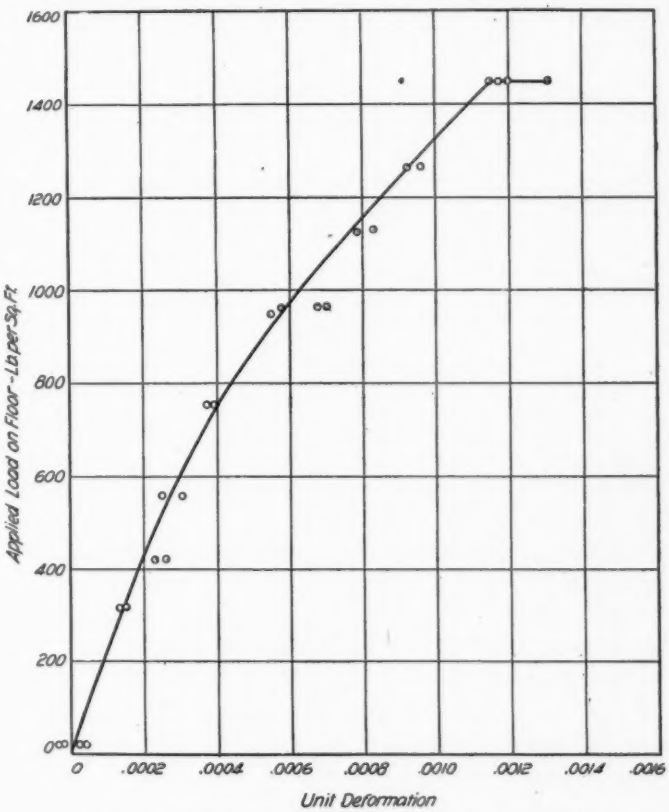


FIG. 20.—Load-Deformation Curve for Floor Steel.

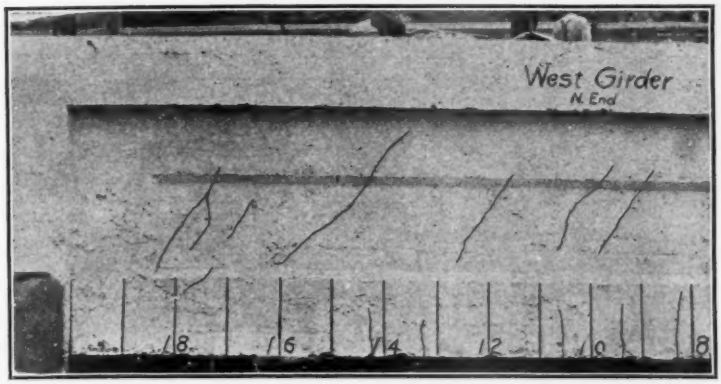
span would develop a stress equal to that measured in the floor steel. In other words, we may assume that the points of inflection of the floor slab are 9 in. from the wheel guard, and that between these points the floor acts as a simple beam. If the floor slab were fully fixed by the girders, the points of inflection would be about 0.21 of the span, or about $3\frac{1}{2}$ ft. from the wheel

guard. These considerations indicate that although the floor is rigidly attached to the girders, its ends have only a slight degree of fixedness, on account of the freedom with which the girders may deflect laterally and tilt inward at the top as the floor deflects under the load. It should be borne in mind that the stresses discussed above are in addition to the dead load stress which has not been considered The computed dead load stress in the floor-slab steel amounts to about 4000 lb. per sq. in. The numerous cracks which were present and the measured deflections indicate that the floor steel was stressed much higher than the girder bars.

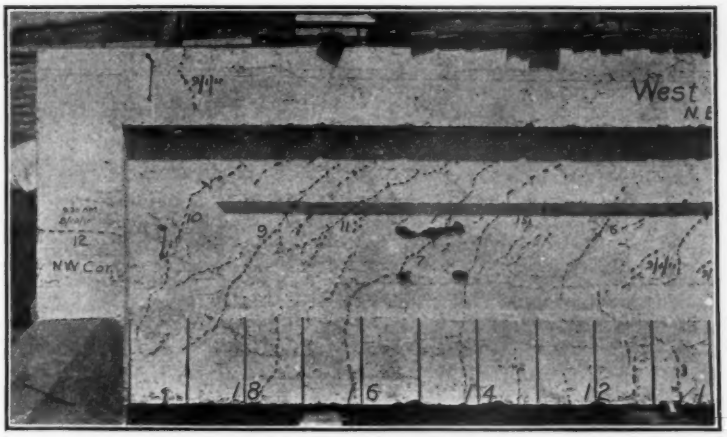
Cracks in Girders and Floor.—Before beginning the last test, the cracks in the girders produced by previous tests were carefully mapped and photographed. These cracks could be traced on each end of both girders, inside and outside. The appearance of the cracks at the beginning of the final test and after the bridge had been subjected to full load is shown for the north end of the west girder in Fig. 21. Photographs were taken which show similar cracks at the other ends of the girders. It was found in many instances during the application of load, that diagonal cracks which had been previously marked had opened again, but at a much higher load than was placed on the bridge in the earlier tests. In some instances new cracks were formed parallel to and near the old ones, and in some cases the cracks which were produced by the earlier tests did not reopen at all, although the girders were subjected to a load many times that which produced the cracks in the earlier tests. It is evident that in being exposed to the weather during three years between the tests, many of these cracks had healed in such a way as to form a joint even stronger than the unbroken concrete. Recent tests made by the writer at the University of Illinois on concrete cylinders in compression and in bond tests with plain bars embedded in concrete exhibit similar phenomena in a most striking manner.

A few vertical hair cracks were formed near the middle of the girders, but in no case did these cracks open wide. The dotted lines on the photographs in Fig. 22 show the extent of these cracks in the middle of the west girder. These cracks extended only a short distance into the concrete, and it is

believed that they were partially due to the lateral deflection of the girders which resulted from the sag of the floor slab. The small size of the tension cracks in the girders confirms the



(*a*) Cracks Produced by Preliminary Loads.



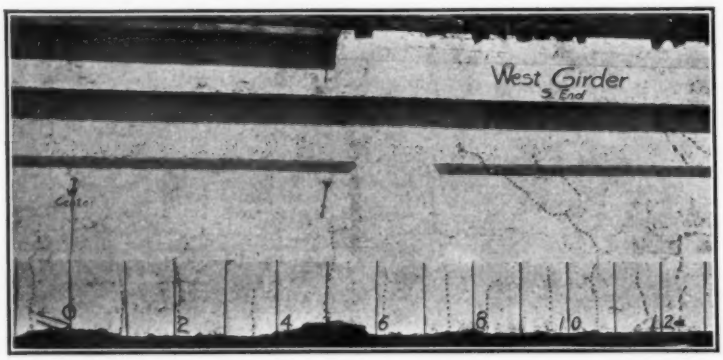
(*b*) Cracks Produced by Final Load.

FIG. 21.—Cracks in North End of West Girder.

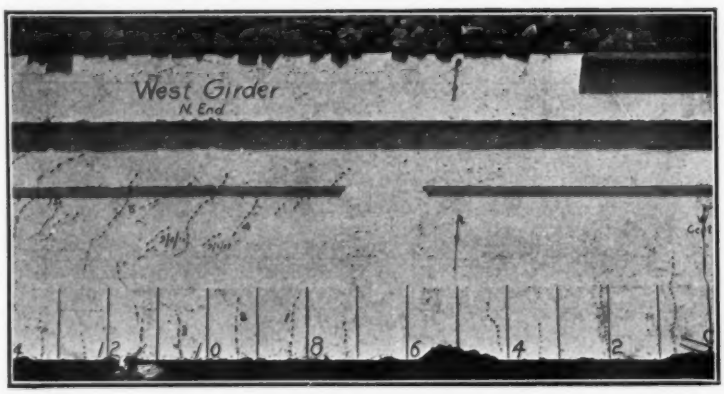
results of the deformation measurements in the longitudinal steel, in showing that at no time was the steel highly stressed.

Cracks in the floor slab were much more prominent and much more numerous than in the girders. These cracks were

well distributed and extended parallel with the girders throughout the middle half of the bridge span. The fine tension cracks which opened in the lower portion of the girders extended a short distance along the lower surface of the floor slab. Fig. 23 shows the approximate position of the principal cracks on the



(*a*)



(*b*)

FIG. 22.—Cracks near Middle of West Girder at Maximum Load.

underside of the floor after the full load had been applied. The figure has been drawn as seen from below. The heavy dotted lines across the corners indicate the position of the cracks on the top of the floor. The top cracks were nearly at right angles to those in the bottom face of the floor slab. They were also

much more prominent than those in the bottom of the floor, and extended well into the floor concrete and up to the middle of the inside of the girders, and in two instances they joined diagonal cracks which had been formed at earlier stages of the test. The appearance of the cracks on top of the floor slab are shown in the photographs, Fig 24. It was found that the deflection of the bridge had caused the ends of the floor to be lifted from the abutments. It is plain that the peculiar condition under which the floor slab is loaded in a bridge of this type, may be expected to produce just the system of cracks which were observed in this test.

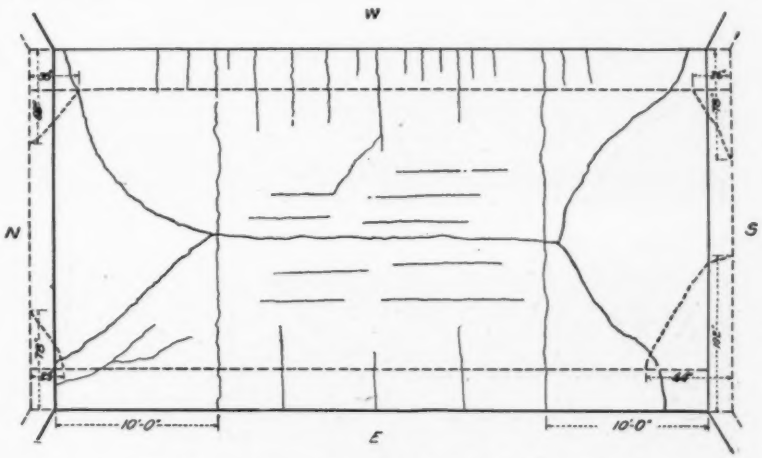
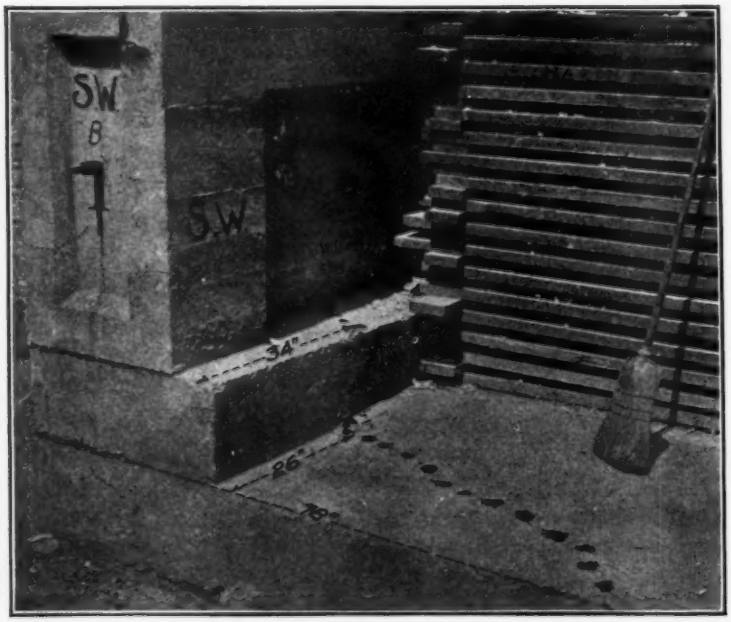


FIG. 23.—Diagram showing Cracks in Floor Slab.

Behavior of the Abutments.—As stated in a previous paragraph, the deflection measurements near the ends of the girders indicated that there was some settlement of the ends of the girders under the load. This can be accounted for by the consideration that the deflection and the inward tilting of the girders produced a highly concentrated bearing stress on the concrete near the outer faces of the abutments which probably resulted in crushing the concrete at these points to the extent shown. The effect of the deflection and tilting of the girders is also shown by the horizontal cracks which formed across the tops of the wing walls and across the ends of the girders as shown in the photographs, Figs. 21 and 24.



(*a*)



(*b*)

FIG. 24.—Cracks in Top of Floor Slab.

SUMMARY.

In arriving at a final estimate of the value of the information derived from this test, it should be borne in mind that at the time of the final loading the bridge was $3\frac{1}{2}$ years old. However, the influence of the age of the concrete was somewhat offset by the unfavorable conditions under which it was built. This bridge of 40-ft. span carried a load for four days which was equivalent to 309 tons per girder, in addition to the weight of the bridge, and the floor slab carried an applied load of 418 tons for over a year, without indication of serious distress. These loads amount to about 9 to 13 times the maximum load which a bridge of this kind would ever be called upon to carry in service. The remarkable load carried by the floor and girders may suggest that the bridge was over-reinforced, or that the design was heavier than necessary; but it should be remembered that the strength of the concrete and the stiffness of the bridge as a whole were very much increased over what we would find in the structure during the first few months after it was put into service.

The behavior of the girders as indicated by the opening of the diagonal cracks in the webs during the preliminary tests, as compared with the final loading, is an evidence of the increased strength and stiffness of the concrete. This calls attention to one of the most valuable properties of reinforced concrete for bridge construction. In the case of a steel structure, great care must be used to prevent deterioration from beginning at once; while bridges of concrete increase in strength and stiffness with the lapse of time and are all the better structures for having been exposed to the weather for several years.

The maximum stress in the longitudinal girder steel, as determined from the deformation measurements, was about 25,000 lb. per sq. in. The stress computed for the same load, under the assumption that the steel of the girders takes all the tensile stress, is 47,000 lb. per sq. in. It will be appreciated that these girders are of irregular form and unusual size; they are not comparable in size and form with other reinforced concrete beams on which tests have been reported. The ordinary assumptions may not apply to a girder of this form and size. The unknown values of the strength and stiffness of the concrete in this bridge is an additional element of uncertainty. The wide

variations between the computed stress in the longitudinal steel of the girders and the measured stress is probably due to the fact that the girders do not act as independent beams, but the entire concrete section and the steel of the floor are also effective in taking the longitudinal stress. The manner in which these stresses were distributed between the girder steel and the floor was not determined; but it is apparent from the general behavior of the bridge, the low position of the neutral axis, and the minuteness of the tension cracks in the girders, that the steel stress was actually comparatively low, and that both concrete and steel of the floor were effective in taking this stress. It is evident that the influence of the floor is much greater at this age than it would have been during, say, the first few months after opening the bridge to traffic. The measurements also indicated that while the compressive stress in the tops of the girders was very high, it was still within the ultimate strength of the concrete.

It was impracticable to compute the diagonal shearing stress developed in the webs of the girders, on account of the irregular section of the girders and the unknown action of the floor, but it is evident that while this stress was very high, the girders were not seriously affected in carrying it. The numerous diagonal cracks in the girders, and the low stresses measured in the vertical stirrups, show that the vertical stirrups provided ample reinforcement against the stresses developed.

The inward tilting of the girders in response to the deflection of the floor shows the remarkable rigidity and strength of the connnection of the suspended floor slab. The detail of the connection of the floor slab to the girders may be considered a distinctive feature of this design for a highway bridge, and its action under an unusual test load gives added confidence to this method of construction.

The load of 418 tons carried by the floor for over a year is equivalent to a uniformly distributed live load of about 1450 lb. per sq. ft. The measured stress in the floor steel under this load was about 34,000 lb. per sq. in., which corresponds to the computed stress, if we consider the effective span of the floor slab to be somewhat shortened by a certain degree of end-fixedness, resulting from the method of attaching it to the girders.

TESTING OF CHINESE WOOD OIL.

By E. W. Boughton.

Introduction.

More analyses and tests have been made on Chinese wood oil than on any other drying oil, except linseed oil. There has, however, been little uniformity of method in the examination of commercial "tung" oils, and the purpose of this paper is to give a comparison of tests and to select the most suitable. Many of the results recorded were obtained with the samples of oil sent out by Sub-Committee C of Committee D-1 for cooperative work. These tests were made in addition to those called for in the directions of the sub-committee to the analysts.

Composition.

According to Lewkowitsch,[1] Chinese wood oil consists principally of the glycerids of oleic and elaeomargaric acids. "Elaeomargaric" acid, which he prefers to the name "elaeostearic" acid, used by some others, is an isomer of linolic acid ($C_{18}H_{32}O_2$). Fahrion's valuable book[2] gives a great deal of information concerning the technology and nature of Chinese wood oil, but he devotes little space to the detection of adulteration with other oils. Quoting Majima,[3] he gives the formula of α-elaeostearic acid as $CH_3.(CH_2)_3.CH{:}CH.(CH_2)_2.CH{:}CH.(CH_2)_7.COOH$. This differs from linolic acid in the position of the double bonds. Maquenne[4] first examined the polymerization product, β-elaeostearic acid, which bears the same relation to the α acid as elaidic acid bears to oleic acid.

β-elaeostearic acid has recently been examined by Morrell,[5] who separated a white crystalline glycerid from the precipitate which forms when Chinese wood oil is exposed to the light in

[1] *Chemical Technology of Oils, Fats, and Waxes*, 1910.
[2] "Die Chemie der Trocknenden Öle," 1911.
[3] Berichte, 1909, Vol. 42, p. 674.
[4] Comptes rendus, 1902, Vol. 135, p. 698.
[5] *Journal*, Chem. Soc., Vol. 101, p. 2082 (1912).

sealed bottles. This gylcerid absorbs oxygen rapidly, and the products of oxidation include an aldehyde formed from the decomposition of a peroxide. The total gain in weight obtained by complete oxidation was 23 per cent. From the white gylcerid Morrell separated the β-elaeostearic acid, melting point 72° C., which he says is a stereoisomerid of α-elaeostearic acid, melting point 48° C.

SOURCE AND PROPERTIES.

It has been well established that the oils known commercially as Chinese wood, Japanese wood, or tung oils are the products of several varieties of trees. An article reporting the work of W. B. Helmsley,[1] which is probably the most authentic and complete recent communication on the subject, states that the Chinese Tung-Yu, the source of the true Chinese wood oil, is not *Aleurites cordata*, as commonly supposed, but a very distinct species, *Aleurites fordii*. The author in making the report stated: "It is certain that *Aleurites cordata*, R. Br., affords a similar product. The confusion has been very great in this intricate subject, and has been partly the result and partly the cause of a confusion that has prevailed with regard to their economic properties. The oil is frequently adulterated with oil from the seeds of *Glycine hispida*, Maxim. (soya bean oil), which seriously affects its drying properties."

A paper by Chapman[2] contains much valuable information regarding Chinese and Japanese oils. The seeds from which he prepared his samples of Japanese oil were from *Paulownia imperialis*, which is entirely different from the "Aleurites." This oil had lower specific gravity, iodine number, and refractive index than his samples of commercial Chinese wood oils. He said: "There is no doubt that Chinese wood oil, like all other oils, varies within certain limits, both in respect to its chemical and physical properties. As a matter of fact, botanical and geographical origin, climatic variations, differences in treatment during the manufacture of the oil, and the duration and conditions of storage unquestionably affect its properties." He might have added that this variability of source and nature

[1] *Bulletin Miscellaneous Information*, Royal Kew Gardens, 1906, p. 117.
[2] *Analyst*, Vol. 37, p. 543 (1912).

is much greater with Chinese wood oil than with any other common oil.

Guiselin[1] states that the oil imported into France is of two distinct kinds, one the product of "Elaeococca," and the other of "Aleurites."

Lewkowitsch[2] states that commercial tung oil is prepared from *Aleurites cordata* or *Aleurites fordii*, or from mixtures of the nuts of the two.

Although both the Chinese wood oil and the Japanese wood oil are called tung oils, it seems advisable, as Kreikenbaum[3] has suggested, to keep the two kinds separate in name.

A recent circular[4] on the Chinese Wood Oil Tree (*Aleurites fordii*), by Fairchild, states that it remains to be determined whether American-grown trees produce as good a product as the Chinese trees. The trees have grown and fruited well in South Carolina, Florida, Alabama, Louisiana, Mississippi, Georgia, and Texas.

TESTS ON CHINESE WOOD OILS.

There are four distinct species of the genus Aleurites:[5] *A. fordii; A. cordata; A. moluccana; A. trisperma.* The samples reported upon in a previous paper[6] on Chinese wood oil, from the Contracts Laboratory, were prepared from nuts of *Aleurites fordii.*[7] The constants of these light yellow, clear oils, were as follows:

CONSTANTS OF TWO SAMPLES OF OILS FROM *Aleurites fordii.*

Determination.	Oil No. 6.	Oil No. 7.
Specific gravity (15°.6 C./15°.6 C.)	0.9421	0.9423
Refractive index (15°.6 C.)	1.5211	1.5239
Saponification number	193.1	191.4
Acid number	0.4	1.4
Unsaponifiable matter, per cent	1.2	0.7

[1] *Matieres Grasses*, Vol. 3, pp. 1689–91, 1729–31, 1762–64 (1910).
[2] *Chemical Technology of Oils, Fats, and Waxes*, Vol. 2, p. 61 (1909).
[3] *Journal of Industrial and Engineering Chemistry*, Vol. 2, p. 205 (1910).
[4] *Circular No. 108*, Bureau of Plant Industry, Department of Agriculture.
[5] Helmsley. *Bulletin Miscellaneous Information*, Royal Kew Gardens, 1906, p. 119.
[6] *Proceedings*, Seventh International Congress of Applied Chemistry, Sect. 1, 1909, p. 89.
[7] The nuts were identified by F. V. Coville, of the Bureau of Plant Industry.

The specific gravity of these samples is higher than that (0.9404) of a sample of oil from *Aleurites fordii* which was examined at the Imperial Institute.[1] The iodine number of the latter oil was given as 166.7, but the method of making the determination is not stated.

An examination[2] of the nuts which yielded oil No. 6 gave the following results:

Hulls	39.72 per cent
Kernels	60.28 "

Analysis of Kernels

Ether extract	62.28 per cent
Crude fiber	3.52 "
Ash	2.93 "
Nitrogen-free extract and water	30.97 "

Analysis of Pulp after Oil is Expressed

Fat	38.03 per cent
Ash	4.66 "

A sample of oil was prepared for the Contracts Laboratory of the Bureau of Chemistry from seeds of the Japanese *Aleurites cordata*.[3] An examination of the seeds, which were smaller than the usual Chinese product, gave the following results:

Kernels	59.06 per cent
Hulls	40.94 "

Analysis of Kernels

Moisture	1.33 per cent
Ash	2.95 "
Ether extract	21.87 "
Protein	15.63 "
Crude fiber	2.09 "
Nitrogen-free extract	56.13 "

Analysis of Hulls

Moisture	10.09 per cent
Ash	1.95 "
Ether extract	1.12 "
Protein	3.19 "
Crude fiber	69.59 "
Nitrogen-free extract	24.06 "

[1] Lewkowitsch, *Chemical Technology of Oils, Fats, and Waxes*, 1910.

[2] Made by J. S. Chamberlain, of the Miscellaneous Division, Bureau of Chemistry.

[3] Obtained from the Office of Seed and Plant Introduction and Distribution, Bureau of Plant Industry.

The clear yellow oil, which had a bacon-like odor, similar to that of the Chinese wood oil, showed the following constants:

Specific gravity (15°.6 C./15°.6 C.)	0.9367
Acid number	1.8
Saponification number	194.3
Refractive index (15°.6 C.)	1.5056
Ash	trace

The pulp left after expressing the oil showed on analysis:[1]

Moisture	7.95 per cent
Ash	3.39 "
Ether extract	3.39 "
Protein	13.00 "
Crude fiber	43.62 "
Nitrogen-free extract	28.09 "

A sample of the seeds of the *Aleurites trisperma* from the Philippine Islands[2] yielded a clear yellow oil, with a bacon-like odor and the following constants:

Specific gravity (15°.6 C./15°.6 C.)	0.9350
Acid number	14.4
Saponification number	195.5
Ash	trace

The oil cake after the expression of the oil showed on analysis:[3]

Moisture	4.23 per cent
Ash	3.27 "
Ether extract	15.63 "
Protein	20.63 "
Crude fiber	41.08 "
Nitrogen-free extract	15.16 "

The oil from *Aleurites moluccana*, which is also called *Aleurites triloba*, is known as candlenut oil, lumbang oil, or kukui oil. Its odor and taste are bland, entirely different from the tung oils, and its iodine number, when determined by the

[1] The analyses of the kernels, hulls and pulp were made in the Miscellaneous Division, Bureau of Chemistry.

[2] Obtained from the Office of Seed and Plant Introduction and Distribution, Bureau of Plant Industry.

[3] Analysis made in the Miscellaneous Division, Bureau of Chemistry.

Wijs or Hanus method, does not vary with slight changes of conditions, as is the case with tung oils. A sample expressed from nuts of *Aleurites moluccana* in the Bureau of Chemistry was light greenish yellow in color, with a faint, mild odor, and gave the following results:

Specific gravity (15°.6 C./15°.6 C.)	0.9269
Acid number	5.4
Saponification number	193.5
Iodine number (Hanus)	149.3
Refractive index at 20° C	1.4777
Ash, per cent	0.02

For the purpose of establishing more definitely the constants of oils of known botanical source, steps have been taken to procure samples for examination in the Contracts Laboratory. With methods of testing standardized[1] it will be possible, by means of such samples, to establish figures for specifications.

The valuation of Chinese wood oil as a commercial product is based largely on its suitability for paint and varnish manufacture, and not on its botanical purity, although the source of nearly all of it is the Tung-Yu, or Tung-Shu tree, *Aleurites fordii*. Adulteration with cheaper or dissimilar oils, however, should be carefully looked for and condemned.

TESTS.

Table I gives the constants of the oils used in the present investigation of methods.

TABLE I.—CONSTANTS OF OILS USED IN THE INVESTIGATIONS.

Oil No.	Specific Gravity, $\frac{15°.5}{15°.5}$ C.	Density, $\frac{15°.5}{4°}$ C.	Saponification Number.	Iodine Number (Hübl, 18 hours).	Acid Number.
1	0.9415	0.9406	197.0	162.6	6.2
2	0.9430	0.9421	199.3	164.8	10.2
3	0.9415	0.9406	196.6	163.1	2.0
4	0.9405	0.9396	195.7	163.0	9.1
5	0.9407	0.9398	197.2	164.4	10.0
6	0.9423	0.9414	196.0	167.7	2.9
7	0.9413	0.9404	198.1	165.4	8.1
8	0.9436	0.9427	196.1	165.1	1.3

[1] Sub-Committee C on Paint Vehicles, of Committee D-1 of the American Society for Testing Materials, is at present engaged upon this work of the standardization of methods. The oils used in part of the work reported in the present paper—a comparison and discussion of tests and methods—and sent out for cooperative work by this committee, were commercial samples purchased from dealers as pure oils.

Specific Gravity.—Although the specific gravity of Chinese wood oil is generally higher than that of most of the common fixed oils, it has not been possible to confirm adulteration by a low specific gravity, since values as low as 0.933 have been published. Lewkowitsch[1] says that the specific gravity of the Japanese oil is lower, from 0.933 to 0.935 at 15° C., than that of Chinese oil. Kreikenbaum[2] gives 0.9401 at 15°.5 C. as a minimum figure. In a previous article from the Contracts Laboratory[3] the specific gravities of six samples ranged from 0.9408 to 0.9428 at 15°.6 C., and that of one sample was 0.9346. Allen[4] gives from 0.936 to 0.943 as the limits. Guiselin[5] states that the oil from the seeds of *Elaeococca vernicifera*[6] has a specific gravity of from 0.934 to 0.9361 at 15°.6 C. The eight samples in Table I vary from 0.9405 to 0.9436 at 15°.6 C. Chapman[7] says that a specific gravity of less than 0.940 is cause for suspicion. He prepared two samples of oil by petroleum extraction, one from the seeds of *Aleurites fordii* and the other from the seeds of the *Aleurites cordata.* The former had a specific gravity of 0.9427 and the latter 0.940. It is to be regretted that Chapman did not determine the other constants of these two oils. He states that they were abnormal in regard to their polymerizing properties. If oils of low specific gravity are not adulterated they are undoubtedly not from *Aleurites fordii.*

There is no information published to show that the oils of low specific gravity are less suitable for use with paint. Manufacturers rely mainly on the iodine number and polymerization by heat tests, and if the sample is satisfactory with respect to these, the specific gravity figure is disregarded. Toch[8] says that Chinese wood oil with a specific gravity of 0.935 would be acceptable if it had a proper iodine number and polymerization. Nemzek[9] says that a specific gravity as low as 0.935 is unusual. He gives the following list of the specific gravities and working

[1] *Chemical Technology of Oils, Fats, and Waxes,* Vol. 2, p. 62 (1909).
[2] *Journal of Industrial and Engineering Chemistry,* Vol. 2, p. 205 (1910).
[3] *Proceedings,* Seventh International Congress of Applied Chemistry, Sect. 1, 1909, p. 89.
[4] "Commercial Organic Analyses," 4th Ed., 1910, Vol. 2, p. 70.
[5] *Matieres Grasses,* Vol. 3, pp. 1689–91, 1729–34, 1762–64 (1910).
[6] Probably *E. Vernicia.*
[7] *Analyst,* Vol. 37, p. 543 (1912).
[8] Private communication from M. Toch, of Toch Bros. and Co., New York City.
[9] Private communication from L. P. Nemzek, of John Lucas & Co., Philadelphia, Pa.

properties of several oils representing different lots, showing that while an oil of standard specific gravity will give good results, other lots of oil of the same specific gravity will not work out entirely satisfactorily, indicating a possible difference in the Chinese wood oil, or suggesting a contamination which is not shown by the specific gravity and which, furthermore, is not detected by the chemical constants or heat test:

SPECIFIC GRAVITY.	WORKING PROPERTY.
0.9402	Satisfactory
0.9396	Satisfactory
0.9404	Not good quality
0.9406	Not good quality
0.9425	Satisfactory
0.9428	Satisfactory
0.9388	Satisfactory

From work done in the Contracts Laboratory the density of Chinese wood oil was found to vary 0.00069 per degree Centigrade between 15° and 50° C. The figure is applicable to most of the tri-glycerid fatty oils.

Refractive Index.—The index of refraction as a means to detect adulteration has been used in the Contracts Laboratory[1] and by Wise.[2] Taking Wise's figures, from 1.5099 to 1.5186 at 25° C., it is evident that an admixture of 20 per cent of such oil as soya bean oil (refractive index, 1.475) would produce a lowering of the reading not greater than the difference between these figures. Chapman[3] says that a refractive index of less than 1.515 at 20° C. is suspicious. Hoepfner and Burmeister[4] report an average refractive index of 1.5175 at 20° C. It is sometimes very difficult to obtain a clear reading with the refractometer.

Melting Point and Cloud Tests.—In oil mixtures of known composition, the writer has been unable to detect the presence of ten per cent linseed, soya bean, or similar oils in Chinese wood oil by such tests as the melting point of the fatty acids and cloud tests.

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[1] *Proceedings*, Seventh International Congress of Applied Chemistry, Sect. 1, 1909, p. 86.
[2] *Journal of Industrial and Engineering Chemistry*, Vol. 4, p. 497 (1912).
[3] *Analyst*, Vol. 37, p. 543 (1912).
[4] *Chemiker Zeitung*, Vol. 37, pp. 18–19, 39. *Analyst*, Vol. 38, p. 116.

Viscosity.—Bacon[1] states that the minimum viscosity of pure oils is 725 on a Tagliabue instrument at 70° F., while old oils run higher, from 760 to 780, and that small adulterations, which can not be detected by chemical means, are shown by a low viscosity figure. In the Contracts Laboratory the viscosity of samples of Chinese wood oil believed to be pure has varied from 873 to 2370 at 20° C. (Engler; water at 20° C. = 100.) The viscosity is permanently changed by warming, by age and by exposure to light, so that the value of the viscosity figure in establishing the purity of a sample is doubtful.

Nitric Acid Test.—Small amounts of Chinese wood oil in certain other oils may be detected by shaking with cold concentrated nitric acid,[2] but this test is of no value when the case is reversed and the detection of adulteration in the Chinese wood oil is desired.

Cobalt or Lead Linoleate Test.—Reihl[3] recommends this procedure for the detection of the presence of adulterants: Heat the oil quickly to 250° C., cool and mix in one per cent of cobalt or lead linoleate. Flow on glass, allowing it to dry for 36 hours; then immerse in water. If the wood oil is pure the film will remain clear and bright. This test has not been tried in this laboratory.

Solubility of Polymerized Oil.—Reihl states that by polymerizing the oil and determining the amount of solid product soluble in benzine, admixture with other oils may be detected.

Iodine Number.—That Hanus and Wijs solutions, when used for the determination of the iodine number of this oil, give concordant results only when all conditions of time, temperature, amounts, etc., are identical, has been shown by Kreikenbaum[4] and in the Contracts Laboratory.[5]

Although the Hübl solution is generally used for this oil, Chapman[6] prefers the Wijs method, using 0.1 gram of the oil, 20 cc. of carbon tetrachloride, and 30 cc. of Wijs solution, allowing the bottles to stand for three hours in the dark. He states

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[1] *Oil, Paint and Drug Reporter*, Vol. 82, pp. 2, 19.
[2] *Proceedings*, Seventh International Congress of Applied Chemistry, Sect. 1, 1909, p. 86.
[3] *Oil and Colour Trades Journal*, Dec. 21, 1912.
[4] *Journal of Industrial and Engineering Chemistry*, Vol. 2, p. 205 (1910).
[5] *Proceedings*, Seventh International Congress of Applied Chemistry, Sect. 1, 1909, p. 86.
[6] *Analyst*, Vol. 37, p. 543 (1912).

that by this method a genuine oil should give a figure not far from 170. I believe that the temperature limits should also be specified. Kreikenbaum[1] recommends a 6 to 7-hour period of absorption (Hübl) and his limits are from 169 to 174. Hoepfner and Burmeister[2] obtained from 156 to 171 (Hübl). Recent work on samples in the Contracts Laboratory shows variation from 163 to 169 (Hübl) for 18 hours absorption. Although many determinations as low as 150 are published, the purity of such samples is not beyond question, and as recent work has shown higher values, the lower limit for the iodine number (Hübl) may be placed at about 160. It is evident that only very gross adulteration with such oils as soya bean or corn oil can be detected by the iodine number.

Assuming that Chinese wood oil does not contain any considerable amount of fatty acids with more than two double bonds, the high iodine numbers that are obtained under certain conditions must be due to substitution. It has been shown in the Contracts Laboratory[3] that this is the case and also that the amount of substitution varies with a change of 15° C. in the temperature of the determination,[4] in which respect the gylcerid of elaeomargaric acid reacts differently from the gylcerid of linolic acid with Hanus or Wijs solutions.

The comparison of the Hanus, the Wijs and the Hübl solutions for the determination of the iodine number has been the subject of several recent papers in chemical journals. The report of the referee on fats and oils of the Association of Official Agricultural Chemists,[5] for 1903, which has seemingly been overlooked by subsequent investigators of this subject, summarizes the effects for many fats and oils very carefully, although it does not include Chinese wood oil.

Iodine Reaction Products Soluble in Petrolic Ether.—McIlhiney's method[6] for the determination of the amount of iodine-reaction products soluble in petrolic ether may prove of

[1] *Journal of Industrial and Engineering Chemistry*, Vol. 2, p. 205.

[2] *Chemiker Zeitung*, Vol. 37, pp. 18–19, 39. *Analyst*, Vol. 38, p. 116.

[3] *Proceedings*, Seventh International Congress of Applied Chemistry, Sect. 1, 1909, p. 86.

[4] In the paper there is an error in the calculation in the table at the top of page 95. The figures for the addition value are too high. Twice the substitution number should be subtracted from the total iodine number to calculate the addition number.

[5] *Bulletin No. 81*, Bureau of Chemistry, Department of Agriculture, p. 46.

[6] *Journal of Industrial and Engineering Chemistry*, Vol. 4, p. 496.

value when enough determinations have been collected to afford data upon which to base limits, but, as the amount of the product that is weighed is a small percentage of the weight of the oil taken, a small variation between duplicates or in the averages for pure oils would render the method useless for detecting anything but very gross adulteration. Determinations made on two oils in the Contracts Laboratory gave 18.6 and 18.9 for one sample, and 14.7 and 15.2 for another. The directions for making the determinations must be more definite than they are at present.

Reaction with Iodine.—The formation of the more or less solid iodine-combination products of mixtures containing Chinese

TABLE II.—TIME REQUIRED FOR FORMATION OF JELLY.

Oil No.	Time, minutes.	Oil No.	Time, minutes.
1	3¼	7	1¾
	3¼		1¾
2	3	8	1½
	2½		1¼
3	2¼	9[1]	1½
	2½		1½
4	4¼	No. 3+10 per cent of Soya Bean Oil	4¼
	3¾		3¾
5	3	No. 7+10 per cent of Soya Bean Oil	3¾
	3		

wood oil as a means of detecting adulteration has been recommended in the Contracts Laboratory[2] and by Browne;[3] Browne's method, taken from Lewkowitsch, is as follows:

One gram of oil in a small dish is dissolved in 5 cc. of chloroform; 5 cc. of a saturated clear solution of iodine in the same liquid is added; and the mixture stirred until a jelly is formed. For comparative results the same iodine solution, free from suspended iodine, must be used. For pure oils the time of setting varies from 40 to 55 seconds, while 10 per cent of soya bean oil causes a rise in this time to 105 seconds.

[1] A very light colored oil: Sp. gr. 15°.6/15°.6 C., 0.9413; Refr. Ind., 20° C., 1.520; Sapon. No., 195.7; Acid No., 5.5.

[2] *Proceedings*, Seventh International Congress of Applied Chemistry, Sect. 1, 1909, p. 86.

[3] *Chemical News*, July 12, 1912, Vol. 106, p. 14.

When using Browne's method upon the present samples, porcelain evaporating dishes, 6 cm. in diameter, were floated in a dish containing water at 25° C. The saturated iodine solution contained 0.04759 gram of iodine per cubic centimeter (titrated against standard sodium thiosulphate). The oil was weighed out to within 1 mg. of one gram; exactly 5 cc. of chloroform were delivered from a pipette, and 5 cc. of the iodine solution added all at once from a small graduate. The time required for formation of the jelly for each oil is given in Table II.

The time for all the oils is considerably above that given

TABLE III.—TIME REQUIRED FOR FORMATION OF SOLID JELLY.

Oil No.	Time, Hours.	Oil No.	Time, Hours.
1	3¼	6	1½
	4¼		
2	3½	7	1¼
	5		2¼
3	1¼	8	1¼
	1¾	No. 3+10 per cent of Soya Bean Oil	2½
4	More than 7 " " "	No. 3+20 per cent of Soya Bean Oil	Over 5
5	3¼		
	4		

by Browne, but it is evident that a 10-per-cent addition of soya bean oil causes such a large increase in the time that this is one of the best means of detecting adulteration. It is very satisfactory in its present form.

Browne does not state the exact strength of his iodine solution, and as the solubility of iodine in chloroform or carbon tetrachloride varies greatly with the temperature, this figure must be known. The stronger the iodine solution, the more rapid will be the formation of the jelly. The solution used when making the tests recorded in Table II is a saturated solution at about 30° C. (Washington, D. C., summer heat). Iodine is more soluble in chloroform than in carbon tetrachloride. An oil show-

ing a settling time of over four minutes is undoubtedly adulterated, and probably the limit for pure oil should be lower.

Using carbon tetrachloride instead of chloroform as a solvent for the oil (from 5 to 5.1 grams), and a saturated solution of iodine in carbon tetrachloride (0.025 gram of iodine per cubic centimeter), a set of tests were made in glass-stoppered bottles at 25° C., 16 cc. of carbon tetrachloride being used as a solvent, and 10 cc. of the iodine solution. The mixtures were not stirred after the first mixing. The time required for the formation of a solid (not semi-solid) jelly is given in Table III.

These proportions give a longer time of setting, but have no advantage over Browne's shorter method. In either case the temperature, the amounts of oil, solvent and iodine, and the stirring must be the same to obtain concordant results.

Heating Test.—Undoubtedly the most generally used test for Chinese wood oil is the heating test, the observation of the behavior of the oil upon heating so that a solid jelly is formed. Much discussion has arisen recently as to the value of this test and the methods of manipulation.

The Committee on Vegetable Oils and Fats, of the New York Produce Exchange, has adopted the following rules[1] for determining the basis of character and quality of Chinese wood oil:

"SEC. 9. Prime Chinese wood oil shall be pale in color (according to season's production), merchantably free from foots, dirt, and moisture; the total impurities shall not exceed 1 per cent; but, unless otherwise provided for, impurities not plainly adulterations, up to 5 per cent, shall not justify rejection; but allowance shall be made by sellers for such impurities in excess of 1 per cent.

"Otherwise, the oils to be accepted as commercially prime shall show, for viscosity, on a Tagliabue instrument from 7.25 upward; the viscosity to be taken on a viscosimeter at a temperature of 70° F., the process to be followed strictly as advised by the makers of the instrument. The oil to satisfy the requirements of either the Bacon test, or the Worstall test."

"*Worstall's Test.*—One hundred grams of the oil are heated in an open metal pan, 6 in. in diameter, as rapidly as possible, to a temperature of 540° F. The time required to heat the oil from room temperature to 540° F. should be, as nearly as possible, the same each time, 4 minutes being sufficient with gas burners. Hold the oil at or as near 540° F. as possible, stirring until it starts to solidify. Note the time required after the oil reaches 540°, until

[1] *Oil, Paint, and Drug Reporter*, Vol. 82, pp. 13, 25.

it starts to solidify. This should not exceed 7½ minutes for any pure wood oil. When the oil has solidified in the pan, turn it out while still hot, and cut with a knife. Pure wood oil gives a product that is pale, firm, and cuts under the knife like dry bread, not sticking. If the oil requires more than 7½ minutes after reaching 540° until starting to solidify, or if the product is dark, soft, or sticky, the oil should be rejected."

"*Bacon's Method.*—Into a test tube ¾ in. in diameter and 4 in. in length there are transferred about 10 cc. of pure Chinese wood oil. Into another test tube there is transferred a like amount of pure Chinese wood oil adulterated to the extent of 10 per cent. A sample of the oil to be tested is treated in a like manner, and these are placed in a proper support and immersed in an oil bath which has a temperature of about 288° C., so that when the tubes are in it a temperature of 280° or 285° C. (maximum) can be maintained (tubes cause cooling). The oil bath containing the tubes is maintained at this temperature for exactly 9 minutes; the tubes are then withdrawn and the test sample is compared with the pure oil, and the same oil adulterated with 5 and 10 per cent of foreign oil. After the tubes are withdrawn from the oil bath, each tube should be stabbed from the top to the bottom with a clean bright spatula. Pure oil will give a hard, clean, cut, and when the knife is withdrawn the incision will look like a straight line; while oil having as low as 5 per cent adulteration will invariably be softer and the incision will have a peculiar feathered effect; and adulteration of 10 per cent will be soft and pushy; while an adulteration exceeding 12 per cent in many instances will remain entirely liquid. This test has been carefully studied and when properly operated along with pure oil and known-to-be-adulterated oil it affords an excellent method of detecting adulteration."

Hoepfner and Burmeister[1] heat the oil 12 minutes at 310° C. If, under these conditions, the oil becomes so solid that it can be powdered in a mortar, there can be no doubt about its being pure.

Potsdamer's Method.—Potsdamer[2] was unable to obtain satisfactory results by Bacon's method. He claims that by noting the temperature of polymerization while the oil is being heated he could detect a 5-per-cent adulteration with other oils. His method is as follows:

An oil bath is heated to a temperature of from 510° to 525° F. (266° to 274° C.). In the bath two test tubes are arranged to act as an air bath. The samples in smaller tubes are inserted in these tubes so that the oil sample does not extend above the surface of the oil in the bath. The samples are stirred from time

[1] *Chemiker Zeitung*, Vol. 37, pp. 18–19, 39. *Analyst*, Vol. 38, p. 116.

[2] "A Method of Detection of Adulteration in China Wood Oils." L. S. Potsdamer. *Proceedings*, Eighth International Congress of Applied Chemistry, Section 5, Vol. XXV, p. 791.

to time until polymerization just sets in, and the temperature noted.

Potsdamer's figures for pure Chinese wood oil are from 535° to 554° F. (280° to 290° C.), adulteration with soya bean

TABLE IV.—HEATING TEST, POTSDAMER'S METHOD.

Oil No.	Temperature, deg. Cent.
3	283 279
No. 3+5 per cent Soya Bean Oil	284 279
No. 3+10 per cent Soya Bean Oil	278 282
No. 3+20 per cent Soya Bean Oil	280 279

oil and paraffin oil causing a drop in the polymerization temperature. As the reaction is exothermic, the thermometer with which the tung oil is stirred reads higher than that in the bath. We

TABLE V.—HEATING TEST, MODIFICATION OF POTSDAMER'S METHOD.

Oil No.	Temperature, deg. Cent.	Oil No.	Temperature, deg. Cent.
1	298 295	8	293 293
2	295 293	No. 1+15 per cent Soya Bean Oil	310 313
3	293 295	No. 8+15 per cent Soya Bean Oil	300 300
4	290 293	No. 8+15 per cent Cotton-seed Oil	295 295
5	295 293	No. 8+15 per cent Corn Oil	303 305
6	288 288	No. 8+15 per cent Linseed Oil	298 300
7	293 293		

were unable to check Potsdamer's figures for oil mixtures, as is shown in Table IV.

Modification of Potsdamer's Method.—If the method is modified as follows different results are obtained: The bath is started

at from 266° to 274° C. and at the last part of the test raised slowly so as to cause the temperature of the tung oil, after it reaches 250° C., to rise 5° C. a minute until polymerization takes place, when the temperature is noted by the thermometer in the tung oil. This modification in the hands of the author gave better results than the original method as printed. The temperatures are not corrected for emergent stem. This procedure gives the figures shown in Table V.

Our experience with Bacon's method agrees with Potsdamer's, and though much information might be gained by the use of the test by an exper' of long experience who had acquired an accuracy of judgment based on the behavior of different samples, the test is not as good in general as Browne's method. We have found nine minutes an insufficient time.

Browne's Method.—Browne's method,[1] possessing more advantages than any of the foregoing methods, gives very concordant results. We quote from his article:

"Test tubes for containing the oil were 16 cm. by 15 mm. with a mark near the bottom to indicate 5 cc., and closed by a cork so perforated that a glass rod 3 mm. in diameter could move freely.

"*Bath.*—This was a copper beaker, height 12 cm., internal diameter 6 cm., filled with cotton-seed oil to a height of 7.5 cm.

"*Thermometer.*—The length was 30 cm. The graduations were from 100° to 400° C., and were verified by comparison with a standard instrument. In the experiments the thermometer was placed so as to be 1.5 cm. from the bottom of the bath. In ascertaining the temperatures of the bath, due attention was given to the cool column of the mercury, so that corrected temperatures are recorded.

"*Method of Procedure.*—When the bath temperature is 293° C. (560° F.) and very slowly rising at this point, the tube containing 5 cc. of the oil to be tested is fixed in so that the bottom of the tube is level with the lowest part of the bulb of the thermometer. The time is noted, and the source of heat is removed for about 45 seconds and then reapplied. Before two minutes have elapsed the temperature of the bath will have fallen to 282° C. (540° F.), at which point it should be kept as steady as possible. When the wood oil has been in the bath about 9 minutes, the glass rod is raised at intervals of half a minute, and when the rod is firmly set the time is again noted. As setting or jellying takes place within a few seconds of fluidity, a good end determination is afforded. The specimen is at once removed, the bath is again heated to 293° C., and the experiment is repeated with another portion of the sample. There is no difficulty in obtaining results which do not differ by more than

[1] *Chemical News*, July 12, 1912, Vol. 106, p. 15.

half-a-minute. No stirrer is used in the bath. A screen around the bath enables the temperature to be more easily reached. When the cotton-seed oil has become tarry and viscid, it should be renewed; otherwise heating may be irregular. The jelly may be removed by half filling the tubes with strong sulphuric acid and placing in a warm place a few hours."

The number of minutes required to form a jelly for seven samples examined by Browne varied from 11 to 13. An addition of 10 per cent of soya bean oil, peanut oil, mineral oil or cotton-seed oil raised the time of setting to 13 or 15 minutes, and 20 per cent of the same oils to 16 or 17 minutes. Browne says:

TABLE VI.—HEATING TEST, BROWNE'S METHOD.

Oil No.	Time, minutes.	Oil No.	Time, minutes.
1	15½ 15	8	11 11
2	13 13	9	12½ 12½
3	13 14 12½	No. 3 +10 per cent Soya Bean Oil	15 16
4	14 15 14	No. 8 +15 per cent Soya Bean Oil	14½ 14
5	15 15	No. 8 +15 per cent Cotton-seed Oil	14½ 15
6	12 12	No. 8 +15 per cent Corn Oil	14 15
7	13 13	No. 8 +15 per cent Linseed Oil	14 15

"The results show that a heat test carefully applied is of considerable help in ascertaining quality. If the time required does not exceed 12½ minutes the oil is in all probability genuine. For heat tests of 13 minutes further examination is desirable."

Figures obtained upon the oils whose constants are given in Table I, are recorded in Table VI. The temperature of the oil in the bath during the test was regulated as Browne directs, so that the reading on the thermometer was from 7° to 8° C. lower than the specified temperature, this being the amount of correction found necessary with the apparatus. This correction is really a necessary part of the directions for any method that

requires the reading of temperatures above 250° C. on a long thermometer.

Many of the samples show times of setting over the limits given by Browne for pure oil. In some cases the variation in time was one minute for the same oil.

It appears from the results shown in Tables IV, V, and VI that adulteration is not easily shown by the heat test, and it must be remembered that samples which have stood any length of time in bottles, especially in the light, polymerize more easily and quickly than fresh samples.

Kreikenbaum[1] states that he has known samples of Chinese wood oil upon standing several years to lose the property of polymerizing by heat, which has also been observed to be the case in the Contracts Laboratory. He says further that an oil may be unsuitable for use because of the presence of a slimy substance distributed through the oil. If this is allowed to settle out there is no trouble.

Chapman's Method.—Chapman[2] prefers Browne's method to that of Bacon, but uses the following modification:

Two 5-cc. portions of oil are heated at 250° C., one portion for ½ hour and the other for 1 hour, and after cooling, the hardness of the cylinders of polymerized oil is noted, differentiating between "very hard," "hard," and "fairly hard." When cut with a knife or broken across, the cut or fractured surface should be smooth and free from stickiness, and small portions when rubbed in the hand should break into a crumbly mass. This test evidently requires experience with the behavior of pure oils and mixtures.

CONCLUSIONS.

The heat test as given by Browne apparently gives concordant results, and his method of procedure is to be recommended. When many samples of known purity and source have been tested, it will be shown whether Browne's limit of 13 minutes is correct. With conditions better standardized, the Potsdamer test will doubtless be of great value. The iodine "jelly" test

[1] Private communication from A. Kreikenbaum, of the Kreik Varnish Co., Chicago, Ill.
[2] *Analyst*, Vol. 37, p. 543 (1912).

will furnish more information than any other, as far as adulteration is concerned, although Browne's limits may be too low for oil generally considered pure. However, the figures in Table II for the iodine jelly test and those in Table VI for the heat test may contain results that are too high, as the purity of all the oils used was not established. The work must be regarded as showing with certainty only the reliability and convenience of the methods. As the question of the suitability of the oil for paint and varnish purposes is somewhat dependent upon the method of manufacture, individual methods of testing will remain as long as they are found to be of value.

DISCUSSION.

Mr. Bragg.

MR. C. T. BRAGG.—I believe that Mr. Boughton has in his paper the best collection of data on Chinese wood oil I have ever read. I doubt if there is any other place where as much information as he has here collected can be found. While the botanical and scientific sides of the question are very interesting, we are more interested in the adaptability of this oil for certain purposes than in its botanical and scientific features. Those of us who are interested in the paint and varnish business are not so much concerned with the question of the purity of Chinese wood oil as we are in its adaptability for certain purposes. We want it to meet certain requirements. If it meets those requirements we don't care whether it is pure or not. However, it is likely that we will find that a pure oil will meet those requirements, while the adulterated oil will not. I believe that in undertaking the standardization of Chinese wood oil specifications, we are attacking the hardest problem that is before the oil chemist at the present time. Chinese wood oil has a place of its own in American commerce.

Referring now specifically to two of Reihl's tests mentioned by Mr. Boughton in his paper, I wish to say that we have tried both of these tests in our oil laboratory. I do not believe the one headed "Solubility of Polymerized Oil" can be used as a test for the purity of Chinese wood oil, for the reason that we have, at various times, been able to extract small percentages of the polymerized oil itself in petroleum ether. We are not always able to do this, but the fact that we can do it occasionally is enough to condemn the method. The lead-linoleate test is absolutely useless, as I never yet have seen an oil, out of hundreds of samples, that would remain clear under this test. I wish to ask, is Sub-Committee C of Committee D-1 contemplating drawing up standard specifications for Chinese wood oil?

Mr. Voorhees.

MR. S. S. VOORHEES.—This matter is under contemplation, but the committee I think understands that it will be a long time before they can do it.

MR. BRAGG.—I am not so sure of that. There are scattered all over the country a great many individual observers of Chinese wood oil. I say "individual," because each man has been thrown on his own feet in this question. Almost every one knows something about linseed oil, but when you begin to talk about Chinese wood oil, very few of us know anything about it. If we had a committee to draw up standard specifications for Chinese wood oil, I think it could be done very quickly, and I think we would find, after one or two meetings, that it would not be very long before we would know what Chinese wood oil is, commercially. I bring this up not entirely from my own standpoint, because you will find those making coatings for steel structures and rust-proof coatings for steel cars, etc., are using Chinese wood oil more or less. If that is the case, I think it interests all of us vitally, because if we are going to continue using paints and varnishes containing this material, each of us wants to be certain that the paint and varnish he buys under the same trade name will be constitutionally the same at all times, and unless we can standardize Chinese wood oil I don't think we can be certain. Take our bridge and fence tests, for example; what do they amount to if you cannot be absolutely certain of the materials used? If you cannot be positive that you are going to get the same material from time to time, even though you do specify the right material, why these tests? **Mr. Bragg.**

MR. H. A. GARDNER.—This matter is of great interest to all manufacturers of paints and varnishes in this country. Mr. Boughton has proposed a new test to determine the purity of Chinese wood oil, and I think that during the present year this test will be taken up and investigated and standardized. During the past year our committee examined about ten samples of Chinese wood oil bought from the brokers, or obtained from manufacturers and other sources as pure oil, and determined the constants for these oils. I think we already have sufficient data to draw up tentative specifications for pure Chinese wood oil, but I think we should have another year's work on the subject to bring in other tests such as Mr. Boughton has proposed. One test to determine its purity is to heat the oil to 540° F. and hold it there for 7 minutes. The Chinese wood oil during that time is changed from a fluid substance to a very hard, horny, **Mr. Gardner.**

Mr. Gardner. rubber-like mass that can be easily powdered. That test at the present time is sufficient, in my opinion, to give us exact data as to the purity of Chinese wood oil. The test Mr. Boughton has proposed will, I think, give us corroborative data with which to draw up standard specifications.

Mr. Bacon. MR. CHARLES V. BACON.—I have examined about 34 per cent of the Chinese wood oil imported into this country during 1912, and have noted that practically none of the investigators have recognized the different grades of Chinese wood oil; namely, Hongkong, Hankow and Szechuan oil.

They are all somewhat similar, but behave somewhat differently under heat. The Hongkong oil will solidify very much quicker than the Hankow oil, but the determination of the purity by one or two tests, as some have suggested, I do not think can be accomplished, because we must not only consider purity, but also quality, and therefore several different tests will have to be applied to enable one to render a correct opinion. Hongkong oil might solidify very nicely under the method Mr. Gardner has just outlined, but adulteration would rarely be detected.

There seems to be a belief that the main and practically only adulterant used in Chinese wood oil is soya bean oil. This is not so, as there are peanut, rapeseed, teaseed, tallowseed, linseed, fish oil, etc., which are all native to China and are made in and around Hankow.

I have not gone into the botanical end of it, but I am quite positive that all the oil imported into the United States is *Aleurites fordii*, and it is my experience that it is made from substantially the same article, the only difference in my opinion being the way the nuts are handled or treated.

The Hongkong oils are pale and slightly cloudy. The Szechuan oils are also pale and in many instances bright, but under heat they do not bleach in the same manner as the Hongkong oils. They darken a little and when solidified correspond very closely to the Hankow oils, which, before heating, are of a red amber color; the grade brought into this country is generally known as "Fair Average Pale Hankow Chinese Wood Oil." This name, while applied to all oils of a red amber color, has a distinct meaning, and such oils, when solidified under heat of

280° C., will bleach somewhat and solidify in a period very rarely exceeding 7½ minutes, while the Hongkong oil will solidify in 4½ to 5½ minutes, and the Szechuan oils generally resemble the Hankow oils. Mr. Bacon.

The standardization of Chinese wood oil will not be a very hard matter in my opinion, because prior to about December, 1911, the Chinese wood oils were running so uniformly that if you drew a chart for the different tests you would have an almost straight line on every one of the constants. It was not until the latter part of 1911 and the beginning of 1912 that we began to notice peculiarities in the oil. Oils which would solidify in 6½ minutes began to take 10 minutes to solidify, and so on. In fact, out of 34 per cent of the total oil imported into the United States in 1912, which I examined, I was able to pass only 27 per cent as being pure or practically pure.

Any one familiar with the tests applied to Chinese wood oil is aware that he will have to consider both the physical and chemical properties. If he considers only the chemical properties, there is tallowseed oil, which is quite available in China and has practically the same analytical constants as Chinese wood oil.

I have laid a certain amount of stress on the viscosity, and while it may not be a positive test for Chinese wood oil, it serves as a guide, and I might say that the minimum viscosity I have found in pure oil is 654 on the Tagliabue instrument at 70° F., while the average was 703. Taking these different oils and adulterating them with say 5 per cent of soya bean oil will reduce the viscosity of an oil which originally tested 735 down to 637, and 10 per cent will reduce it to 588.

Referring to the samples obtained by Mr. Gardner, I think he will find on looking further into these samples that he struck the market at a very poor time, because when he received his samples of Chinese wood oil, which I think was in March or April, the market was just flooded with adulterated oil, and the tendency of the brokers who had pure oil was not to put it into the hands of anybody who would be able to use it to advantage. I think much of that work and many of the samples Mr. Gardner has received will have to be further looked into, and the opinions rendered should be based upon some standard which has been

Mr. Bacon. customary and recognized by the trade; or the report published without remarks such as "good," "fair," etc.

Mr. Gardner. MR. GARDNER.—Most of the samples we used in our committee work were obtained from large paint and varnish manufacturers, though in two cases we used samples that have been in my own laboratory about three years, and were known to be pure. During the past month I have found a test that offers a great many possibilities, namely, the sulphur-chloride test. When sulphur chloride and carbon tetrachloride are added to Chinese wood oil, solidification immediately takes place. The oil becomes a hard, dry mass. When sulphur chloride and carbon tetrachloride are added to other drying oils, the hardening and heating action takes from 10 to 12 minutes. I think we can show the purity of tung oil by the sulphur-chloride test; in fact, we are going to use this test in the investigations proposed for the coming year.

Mr. Boughton. MR. E. W. BOUGHTON.—Mr. Bragg reports that the cobalt or lead-linoleate test described by Reihl has been found by him to be worthless. Since the preparation of this paper, a paper has been published by Fokin which states that the formula of elaeostearic acid is $CH_3.(CH_2)_3.CH{:}CH.CH{:}CH.(CH_2)_9.COOH$, the double bonds being conjugated. He also states the possibility of the presence of a carbon atom with two double bonds. Wolff has since published the statement that the jelly-like product of the polymerization of the oil is not homogeneous, but that only a small portion of the oil is altered, the unaltered oil being incorporated with the colloidal gel.

As the products of different botanical species have been known as Chinese wood oil, it will be very difficult to establish the meaning of the word "purity" for this oil. Certain desirable characteristics will enable us to pass upon the quality of a sample. Perhaps we may adopt the word "prime," as Mr. Bacon has used it, in judging oil. Whatever the methods of manufacture may be for the preparation of paint or varnish, an oil of certain chemical constants and showing certain values for the heat test and the iodine-jelly test will be a standardized material, so that the manufacturer will know what he is getting, and will know from experience how it will act in his kettles.

OUTLINE OF A TEST FOR INDICATING THE RELATIVE PRIMING AND TOP-COAT VALUES OF DIFFERENT PAINTS.

By M. McNaughton.

The generally accepted conclusion, reached as a result of the experience of the past few years, is that the best protection against the corrosion of iron and steel is not to be secured by the use of any one kind of paint, but by the use of different kinds of paint in combinations. Certain paints are excellent as primers, while others give best service when used as top coatings. The importance of a simple test to determine value of paints in these particulars seems evident. Three years ago the writer started a test with this idea in view, and the results seem to show that the method adopted is capable of being used to considerable advantage. Objection may be made on the ground that the areas covered are too small; but on the other hand, tests of two or more combinations may be made on one piece of steel, thus eliminating uncertainties arising from variations in the qualities of the steel plates.

Briefly the scheme is as follows: The upper half of a steel plate (10 by 16 in. is a good size) is painted with one of the two paints being tested, while the lower half is painted with the other. When dry, the left half of the plate is painted with the first paint, and the right half with the second paint. This is the simplest form of the test, and gives four combinations of coats. The plate may be divided into thirds and three paints tested, giving nine combinations of two coats each. In the test referred to, two paints were tested on each plate, but three coats were applied, the third coat being a duplicate of the second. The paint was normally mixed and normally spread. The steel was not especially prepared except to see that it was clean. The exposure was in a city, on the roof of a factory, one hundred yards from a railroad, and one-half mile from salt water, and with a southeast exposure.

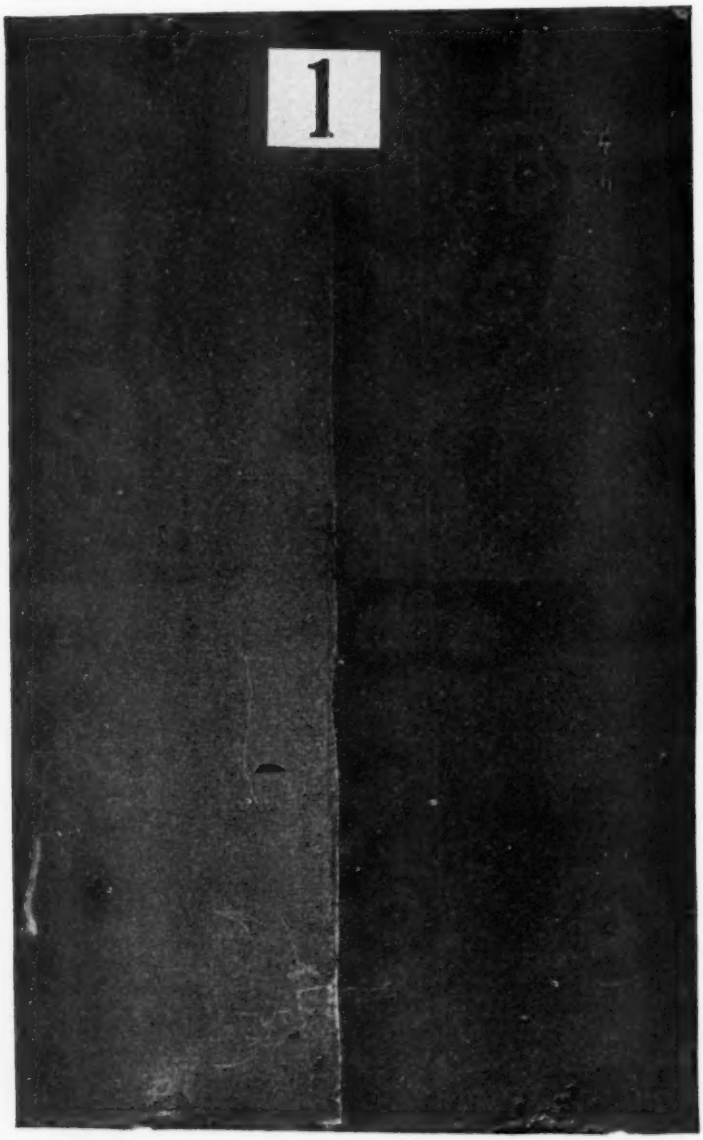


FIG. 1.

	UPPER LEFT	UPPER RIGHT	LOWER LEFT	LOWER RIGHT.
Priming Coat...	Red Lead	Red Lead	Cryst. Graphite	Cryst. Graphite
Second Coat....	Red Lead	Cryst. Graphite	Red Lead	Cryst. Graphite
Third Coat....	Red Lead	Cryst. Graphite	Red Lead	Cryst. Graphite

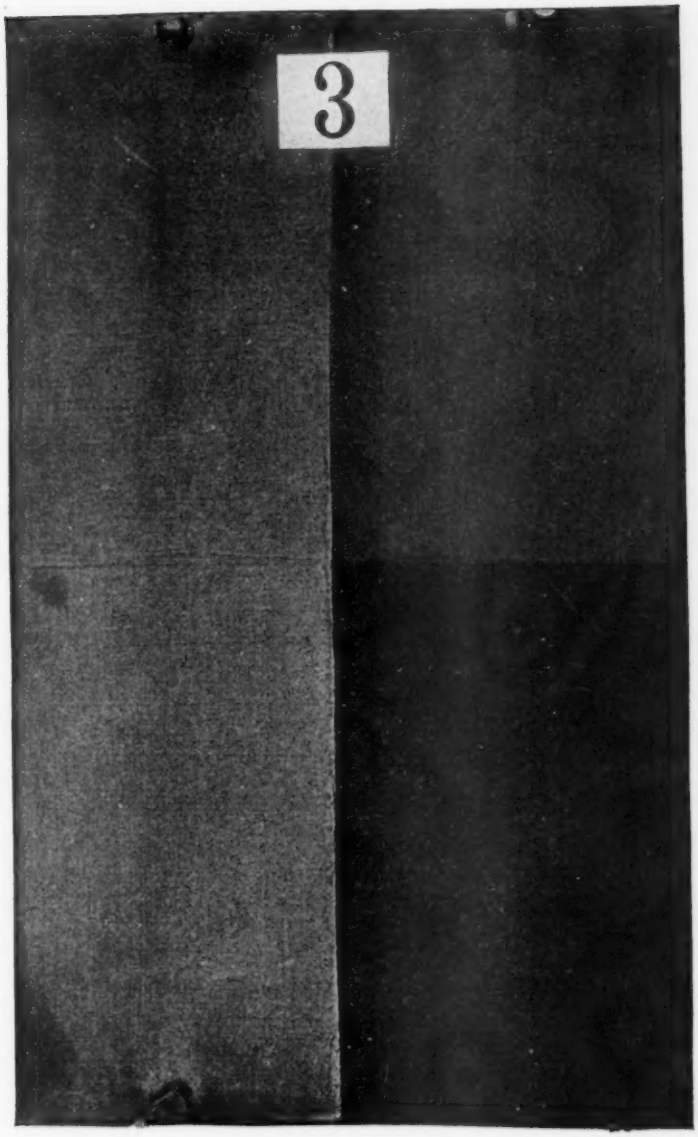


FIG. 2.

	UPPER LEFT	UPPER RIGHT	LOWER LEFT	LOWER RIGHT.
Priming Coat...	Red Lead	Red Lead	Iron Oxide	Iron Oxide
Second Coat....	Red Lead	Iron Oxide	Red Lead	Iron Oxide
Third Coat.....	Red Lead	Iron Oxide	Red Lead	Iron Oxide

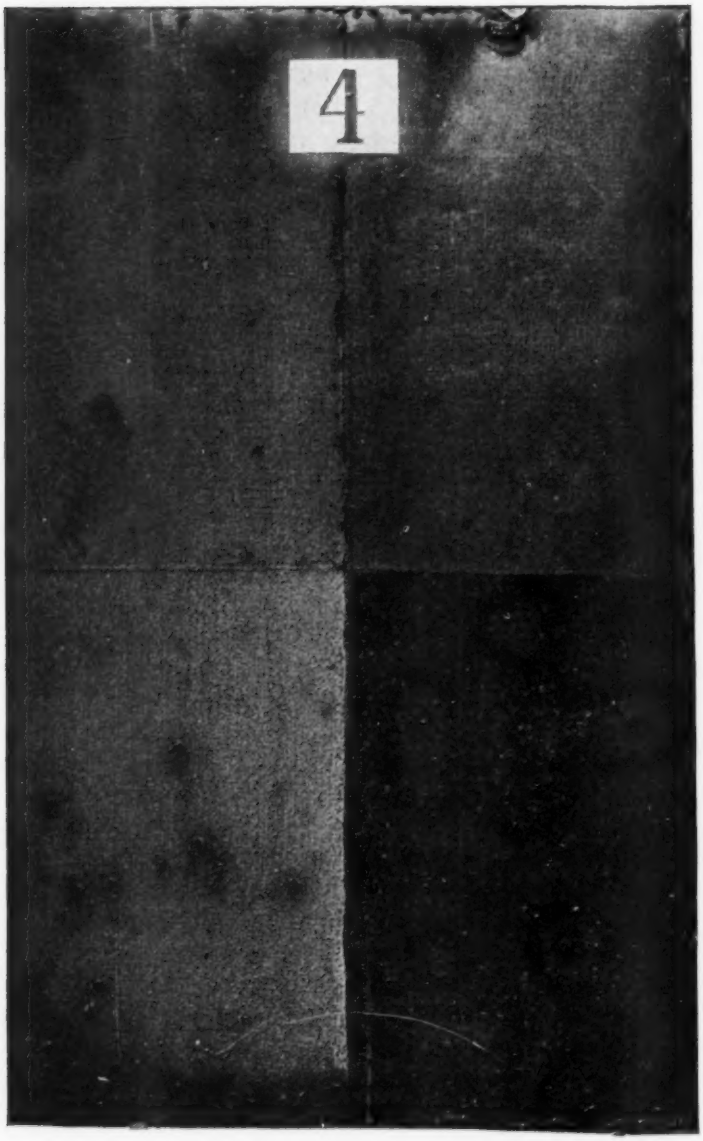


FIG. 3.

	UPPER LEFT	UPPER RIGHT	LOWER LEFT	LOWER RIGHT.
Priming Coat...	Red Lead	Red Lead	Amor. Graphite	Amor. Graphite
Second Coat....	Red Lead	Amor. Graphite	Red Lead	Amor. Graphite
Third Coat.....	Red Lead	Amor. Graphite	Red Lead	Amor. Graphite

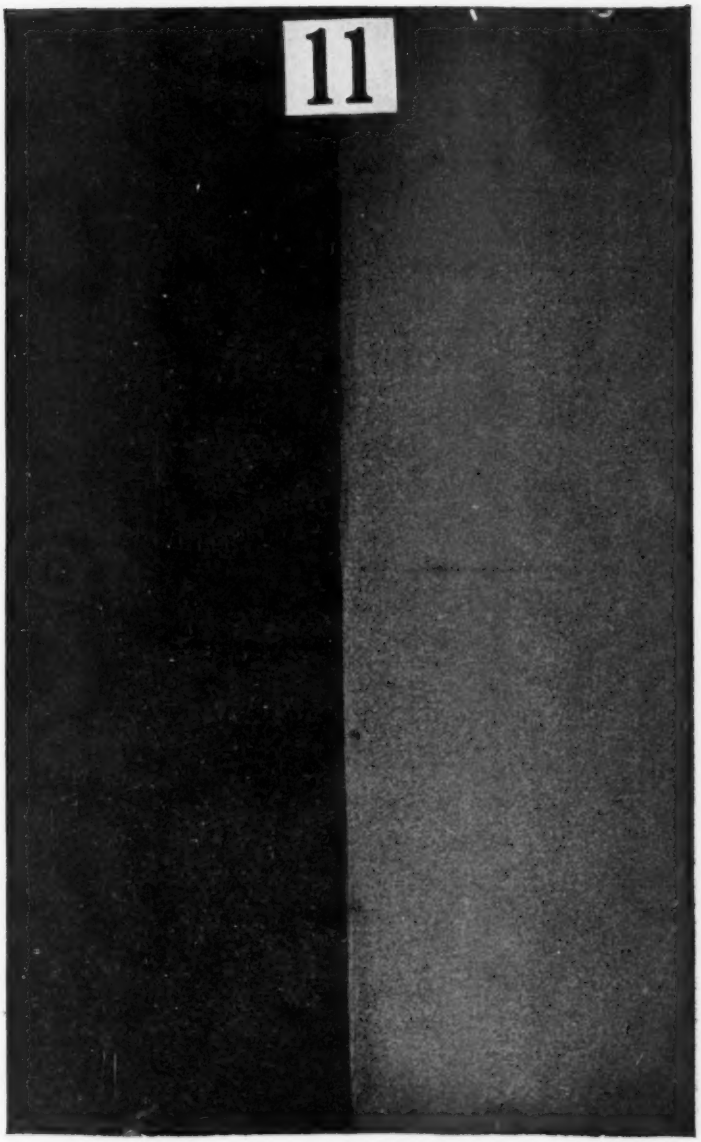


FIG. 4.

	UPPER LEFT	UPPER RIGHT	LOWER LEFT	LOWER RIGHT.
Priming Coat.	Cryst. Graphite	Cryst. Graphite	White Lead	White Lead
Second Coat. .	Cryst. Graphite	White Lead	Cryst. Graphite	White Lead
Third Coat. . .	Cryst. Graphite	White Lead	Cryst. Graphite	White Lead

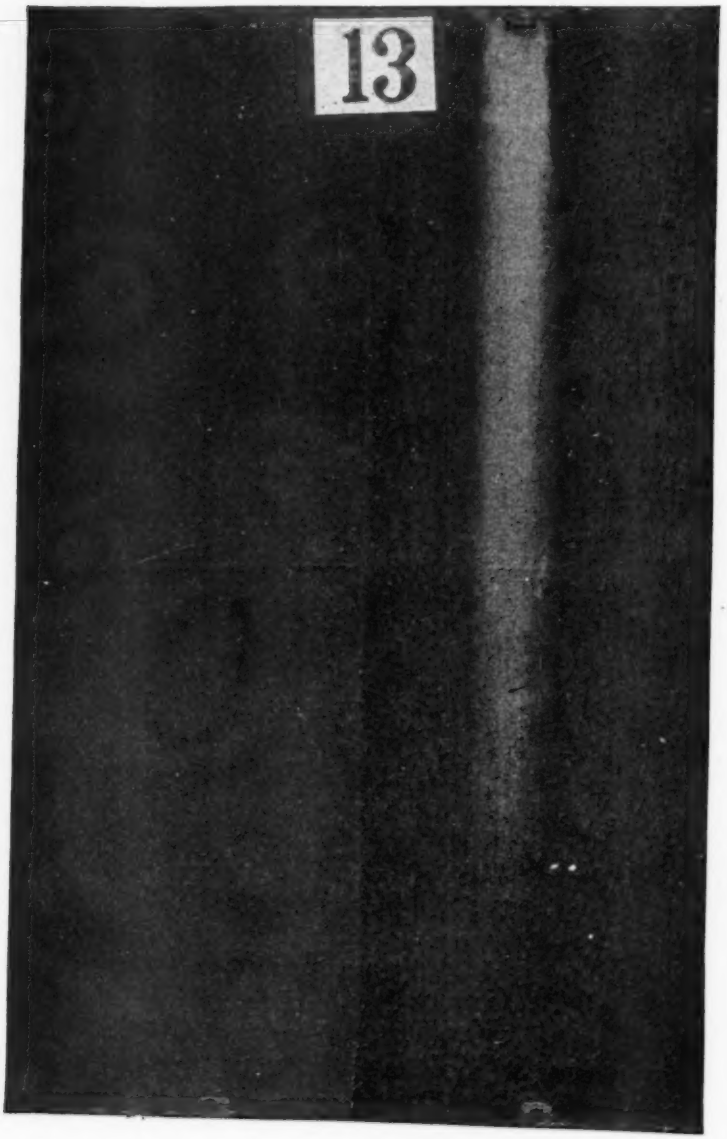


Fig. 5.

It is not the writer's intention to present any conclusions as to the result of the test, as it was not carried on under authority of this Society, but certain characteristic results have been shown which seem to prove the value of the form of test and should therefore be of general interest. These are shown in the five photographic cuts, Figs. 1 to 5, appended hereto.

Attention is called to the difference in tone of the upper and lower right-hand quarters of Fig. 1. This is entirely due to the underlying red-lead coat in the upper quarter, the line of demarcation being its lower edge. The graphite coating over the red lead has retained its luster, while it has lost it when applied over itself as a priming coat.

In Fig. 2, the difference in tone of the right-hand quarters is again caused by the underlying coat of red lead. The upper portion has retained its original brightness while the lower portion has changed to dark brown color.

In Fig. 3, the action of the under coating in preserving the outer coating is still more pronounced than in Fig. 1.

Fig. 4 shows that no action has occurred between these coatings, as no line of demarcation is observable.

Fig. 5 is presented as conveying a possible hint to investigators in the paint industry. The white paint used on this panel was whiting, and is seen to be in almost perfect condition in its central portion. This part was immediately below a point where a brass button was located to hold the plates in position. The ends of the brass button were wound with black rubber insulating tape, as used in electrical work.

It is quite evident that tests made on one plate are much more easily compared than when made on separate plates, with the added advantage of there being no uncertainty as to the character of the metal itself.

DISCUSSION.

Mr. Gardner.

MR. H. A. GARDNER.—I think one point of great importance has been brought out in these and other recent tests, namely, the protective value of calcium carbonate. In the Atlantic City tests which are under the supervision of this Society, pigments which are basic in nature proved to be wonderful inhibitors of corrosion. There is no pigment which has such a wide general use for painting metal as red lead. A red lead with only 6 per cent of litharge in its composition is, however, a practically neutral, inert pigment. Red lead containing about 15 per cent of litharge is very inhibitive and should be used whenever available. Neutral chromate of lead is also a pigment which is inert towards corrosion, while a basic chromate of lead is highly inhibitive. Sublimed blue lead is another basic pigment, containing 35 per cent of litharge in a combined amorphous condition, so that it does not react with linseed oil. This pigment has shown its inhibitive properties for five years in the Atlantic City tests.

Mr. Thompson.

MR. G. W. THOMPSON.—The question as to whether a red lead, containing a relatively high percentage of litharge, is better than one containing a low one, is a matter that can only be determined by practical experiments, where litharge is added to red lead or red leads of various compositions compared practically. There is no doubt, however, but that the highest grade of red lead, that is, the one containing the highest percentage of pigment, is the better pigment, or, in other words, has the best qualities from the paint standpoint. The high degree of oxidation is simply obtained by fine grinding.

Mr. Gardner.

MR. GARDNER.—There is just one process by which 98-percent red lead can be made and not contain sodium in the red lead, and that is to make it by roasting scrap white lead at a high temperature; but such a red lead is not as good as an 85-percent red lead.

COAL-TAR AND ASPHALT PRODUCTS FOR WATERPROOFING.

By S. T. Wagner.

The increasing number of solid-floor bridges, especially in cities, involving waterproofing and the expenditure of large sums of money, and the necessity of thoroughly protecting steel reinforcement in concrete under certain conditions, as well as the waterproofing of masonry in general, make the study of the various external methods of waterproofing of the greatest importance. The methods referred to consist in the application to the surface to be waterproofed of either a membrane of felt or fabric of some kind thoroughly cemented together with some bituminous material, or a layer of inorganic material impregnated with the same substance.

There can be no question but that the bituminous material so used is the real waterproofing medium, and that all other materials incorporated therein are simply fillers to retain the bituminous material in place and give it additional reinforcement of some kind.

Whether the waterproofing is applied for the protection of the public from drippings from an overhead railroad bridge, or is used to prevent the corrosion of reinforcing material in concrete construction exposed to water, the object in either case is to obtain a layer of durable waterproofing material which is suitable to each particular case.

Waterproofing is expensive; it is always very difficult and costly to repair if defective; and it behooves the engineer to use the best materials that he can secure and to apply them with the greatest care to the structure, which should be especially designed to meet the necessary details required in good waterproofing practice. There is much uncertainty at the present time as to a number of points in connection with this character of work, but there appears to be almost complete agreement that the perfect or imperfect application of the materials determines a good or a bad piece of work.

It would appear that, outside of particular instances where waterproofing is used to keep water in, the majority of cases are those in which the object is to keep the water out; and of these a very considerable portion of the structures requiring its use are essentially different as indicated above—first, solid-floor bridges; second, underground masonry.

In the first case the conditions are such as to require special elasticity at all temperatures in order that the waterproofing may adjust itself to the vibrations of the structure, especially in the cases of railroad bridges of relatively short span. It is usual to have a regularly ballasted floor, which if properly drained makes a condition for which we can say in general that the oxidizing action of the air is probably a more potent factor in the disintegration of the waterproofing material than the action of whatever water may be present.

In the second case we may safely say that when the masonry is covered with even a small amount of earth, the action of the air is negligible and that of the dampness, or water, is the more serious. In some instances water may be in constant contact with the waterproofing.

The materials to be used should therefore have chemical and physical characteristics which make them suitable for the above-mentioned conditions.

There are in use at the present time two general classes of materials which are used for waterproofing purposes when the conditions are as just described: First, compounds of an asphaltic nature; second, coal-tar pitch. Both of these materials have been and are at present used quite extensively and with varying success. The successes or failures in many cases have been due to proper or improper application as much as to the inherent qualities of the materials themselves; and it is believed that the successful use of either class has often been attributed to this fact rather than to the real qualities of the materials, and that at the present time the amount of reliable data as to what is needed in the way of a specification for the proper material to be used is woefully lacking.

To one who is not a modern chemist and thoroughly versed in the mystic symbols of the hydrocarbons, the chemistry of these materials is almost hopeless in its practical application;

but it is quite evident that there is an essential difference between them chemically, that is, between such figures as are usually given in chemical analyses.

The physical properties are apparently much more interesting and useful to the practical engineer, and it would seem that we could do away with the chemical data unless they indicate properties which when translated will enable us to distinguish undesirable, or it may be dangerous, elements. We can understand and appreciate such figures as melting point, brittle point, elasticity at various temperatures, and consistency, and data concerning these properties give us a very fair idea of the various physical properties.

The data which seem to be needed are those from laboratory tests which will enable us to determine the relative durability of these products, first, when exposed to the air; second, when exposed to water; and third, when alternately wet and dry. Any such test is, or would be, essentially an accelerated test. It is possible that at the present time the question of durability might have to be answered by practical experience with the different materials in existing structures. However, it does seem that some information as to what we should aim for and what should be avoided is due from the manufacturer or the chemist. Nothing inspires the confidence of the user of a structural material so much as the free discussion of the methods of manufacture on the part of the manufacturers. Experience in the past with other materials has shown that this confidence is not abused in the preparation of specifications. Such information is badly needed in connection with waterproofing materials.

From recent investigations and research there seems to be a general impression that when exposed to the air, asphalt products are more durable than coal-tar products, and that the opposite is true when exposed to water. The opinion that asphalt products are more suitable for use on solid-floor bridges seems to be of general though not universal prevalence, on account of the greater elasticity of this material at low temperatures. In other words, an asphalt product with a melting point of 150° F. which will be ductile at a temperature of 40° F. or lower can be obtained, while a coal-tar pitch with the same properties can not. It has been the experience of the writer

that asphalt mastics made with natural rock asphalts, when fluxed with asphalt compounds of high ductility at low temperatures, produce mastics which are much less liable to crack in service than are those in which the flux used is brittle when cold.

Water to a certain extent is a solvent of all asphalts, but from the tests of Whipple and Jackson[1] it is quite evident that the question of solubility is a comparative one, and the tests there given show that there are classes of asphalts upon which the action of water is very slight. In this paper a quotation is made from Richardson[2] which shows that the action of water upon coal tar is about two-thirds of that upon Bermudez asphalt cement when expressed as the gain in weight in water in a given time. Bermudez asphalt in the tests made by Whipple and Jackson is among those which were most affected by water. A number of cases of the durability of coal-tar pitch in actual service in underground work seem to indicate very positively its suitability for this class of work. Will some one say whether or not properly selected asphalts are unsuitable under similar conditions?

Apparently the questions which need to be answered are the following:

1. What kind of materials are most suitable for general application to (*a*) solid-floor bridges; (*b*) underground masonry?
2. What kind of materials are most durable for (*a*) solid-floor bridges; (*b*) underground masonry?
3. If asphalt products are used, what should be specified?
4. If coal-tar products are used, what should be specified?

Probably the answers to these questions belong to the work now under consideration by Committee D-8 on Waterproofing Materials, but a general discussion of the subject may be of material assistance to the committee in its work.

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[1] *Proceedings*, Brooklyn Engineers' Club, March 8, 1900.

[2] *Municipal Engineering Magazine*, June to August, 1897.

DISCUSSION

Mr. P. P. Sharples.—Coal-tar products for waterproofing purposes have been used for many years and have been found very satisfactory indeed, both for underground work, and for overhead work with full exposure to the air. A very large amount of coal-tar pitch is used for roofing. In the case of the tar-and-gravel roof, the coal-tar pitch is exposed directly to the air, so there is no question but what coal-tar materials are entirely suitable for use in waterproofing bridge structures. **Mr. Sharples.**

In the list of tests suggested for waterproofing materials Mr. Wagner has omitted any test which would show whether the materials will reunite when once fractured. In any structure where the waterproofing is subjected to bending or tearing strains, the property of reuniting is essential to successful and lasting work.

In specifications it has been usual in this country to specify that the coal-tar pitch shall be a straight-run coal-tar product, and to specify its melting point by the usual cube method. This simple specification has usually brought forth materials that have been satisfactory.

Mr. C. N. Forrest.—Mr. Sharples has just put in a word concerning coal-tar pitch for waterproofing purposes, so I rise as an exponent of asphaltic products, as both classes of substances have been mentioned in the paper by Mr. Wagner. **Mr. Forrest.**

Asphaltic products have been used successfully under both ground and water, as well as above ground, just as coal-tar products may have been used with success above ground as well as under ground and water. The tests of Whipple and Jackson, which have been referred to in Mr. Wagner's paper, are rather ancient. As I remember them they were conducted by treating the asphalt and various other substances contained in glass bottles with water and estimating the amount of soluble matter taken up by the water after a period of time. The chances are that more soluble matter came from the glass of the bottle than from the bituminous substance. I think one of the chief diffi-

Mr. Forrest. culties in the way of securing bituminous products which will be suitable for waterproofing purposes is that the specifications are entirely too general. The terms "asphalt" and "coal tar," as usually employed in specifications and also as referred to in the paper under discussion, are too general. There are many different classes or types of both of these substances, all of which have to be, or should be, prepared for specific use.

Some manufacturers who are interested in the exploitation of waterproofing materials have issued directions for the use of their products, and one in particular has supplemented such directions with quite definite specifications covering different classes of bituminous cements and recommendations as to their use. I do not think that there is any doubt that asphaltic mastic furnishes the highest type of waterproofing system. That also seems to be the opinion of the author of the paper. It is, unfortunately, the most expensive form, as it must be applied by skilled labor which may have to be transported a long distance. On the other hand, the application of the so-called membrane method of waterproofing may be done by local talent just as the ready roofings are applied, and many failures of that type of work may be due to careless work, quite as often as to the use of improper materials. The tendency of engineers in the selection of asphaltic products appears to be to get as far away from the general nature of coal-tar products as they possibly can. A sample which in the hand is of a rubbery nature and attractive looking may be given preference, although some more fluid and highly cementitious compound would be much better for the purpose. On account of the inherent properties of bituminous substances in general, rubbery characteristics may only be secured by sacrificing other and sometimes more important characteristics. Coal-tar pitch, we know, is a very adhesive, ductile material and has the property of self-healing, as the former speaker has remarked, which is very desirable in a waterproofing system. On the other hand, those ashpaltic products which are very resistant to wide fluctuation in temperature, and are of a rubbery nature, are noticeably lacking in that respect.

The former type of materials are cements while the latter more closely resemble greases. Intermediate, between the

extremely fluid and brittle coal-tar products and the extremely viscous and non-brittle asphaltic, or perhaps more correctly speaking, petroleum products, are the natural solid asphalts which possess a fair balance of adhesive and cohesive properties, and are suitable for a wider variety of waterproofing purposes, both as mastic or plying cement with felt or fabric membrane, than either of the extremes just mentioned. **Mr. Forrest.**

A great deal of material which is only suitable for use as a filling for expansion joints has been used as a cement between felt or a fabric, and found to be unsatisfactory on account of a lack of sufficient adhesive properties.

MR. W. H. KERSHAW.—There is another point that has not been touched by Mr. Forrest, with whose remarks I agree fully. In the extensive use of bituminous waterproofing materials by railroads on their steel bridges and also on their underground masonry, which often carries conduits, the engineer frequently looks for a material that will not only act as a waterproofing agent, but that also possesses some insulating properties. It strikes me that, without knowing the particular needs of the engineer, it would be a great mistake to attempt to outline specifications, even in a general way, or to attempt to answer the four questions asked by Mr. Wagner. **Mr. Kershaw.**

MR. S. T. WAGNER.—My principal object in the preparation of the paper was an endeavor to obtain in the discussion information that might be of value in the preparation of reasonable specifications for the materials used in waterproofing. It is undoubtedly true that conditions govern the character of the material to be used and that these conditions vary greatly. The two conditions especially mentioned in the paper, namely, (*a*) solid-floor railroad bridges, and (*b*) underground masonry, are those of particular interest to me. It would not only be impossible but also unwise to attempt to make specifications that would be applicable for all purposes. For that reason the questions asked in the paper were confined to definite lines. **Mr. Wagner.**

MR. BENJAMIN FOSTER (*by letter*).—A discussion of the various points involved in the proper and economical solution of waterproofing problems by the membrane method is resolved into two divisions; first, the waterproofing of solid-floor bridges, second, the waterproofing of building construction. The radi- **Mr. Foster.**

Mr. Foster. cally different conditions which obtain as to contact with water, contact with air, and variations in temperature are such that the application of a method satisfactory for the one purpose will not necessarily serve equally well for the other.

It is only in comparatively recent years that systems of waterproofing have come into general use. Such information as may be contained in this paper, however, is the result of fifteen years' experience in this class of work.

Reverting again to the two divisions of problems, it may be stated that the waterproofing of bridges is relatively simple compared with waterproofing the foundations of buildings. In the one case the waterproofing system is applied for the purpose of shedding water in a way somewhat similar to the waterproofing roof construction; in the other, pressure must be considered, and there is no opportunity of devising a design that will dispose of the water by the aid of gravity.

After a wide discussion of this subject with architects and railroad engineers, it would appear that there has been entirely too much time and effort consumed in the discussion of the technical constituency of the materials to be used, at the expense of a careful consideration of the manner and method of application. If means of shedding the water are important, even more so is the establishment of connections that will effectively and permanently seal the waterproofing course. Instances can be cited by the writer where tremendous expenditures for waterproofing systems have been of no avail, owing to the fact that no proper provisions had been made for the sealing and waterproofing course. Without connections that can be depended upon indefinitely the work soon becomes valueless.

After the manner of application has been designed in the most careful and effective way that conditions will permit, there comes the question as to the kind and quality of bituminous materials to be used. Various preparations of coal tar and asphalt have been found to accomplish the desired results, when applied to meet conditions which the waterproofing selected is able to resist. Good materials used in the wrong place are, however, as apt to be productive of bad results as when poor materials were used originally.

Unfortunately, there are on the market numerous prepara-

tions listed under the head of coal tar and asphalt, which are absolutely worthless under any conditions—cheap and ineffective substitutes for the higher-grade materials that a satisfactory job necessitates. The worst feature of the situation, from the viewpoint of the engineer or architect, lies in the fact that it is impossible for one inexperienced in handling such materials to distinguish the difference between the two. Mr. Foster.

The progress of practical laboratory methods, up to the present time, has not been such as to enable the analytical chemist to differentiate between good and bad waterproofing compounds. In fact, the laboratories of certain unscrupulous manufacturers have made far greater progress, as evinced by their ability to manipulate formulas in such a manner as to permit deductions that practice readily disproves. In certain cases worthless materials appear to possess a much higher grade, if the results produced by the legerdemain of the subsidized chemist be accepted as worthy of credence.

The lack of dependable laboratory methods is shown by the fact that numerous instances are known to the writer where practically worthless materials, susceptible of ready deterioration, have been submitted to reputable laboratories and accepted in accordance with specifications, and the cost of manufacture thereby reduced 50 per cent.

In using the membrane system of waterproofing, the adoption of a suitable carrying material or binder is of the utmost importance. Various agencies are utilized—wool felts, asbestos, felts, canvas, burlap, etc.—as a base for saturation with the various bituminous compounds. Fabrics, or reinforced felts, find greater favor on account of their toughness, which holds the waterproofing together in a uniform mass and aids in the prevention of openings by various causes.

At this point the writer wishes to strongly emphasize the fact that it is not possible to obtain the same efficiency from single heavy plies as from thinner plies of saturated felt used in such number as the work may demand. Furthermore, a perfect, homogeneous bond must be secured in all instances or the effectiveness of the membrane system of waterproofing is greatly lessened or destroyed. Some argue that the heavy fabrics or reinforced felts, because of their great toughness, prevent punc-

Mr. Foster. turing or cracking. Nevertheless, when a surface is at all suited to receive the membrane system of waterproofing, such protection is not necessary, provided the proper number of plies have been used.

An instance in point is a building that had been waterproofed for a ten-foot head of water, with bituminous material and saturated fabrics which were apparently of the highest grade that could be obtained and applied in the best possible manner. After excavations had been filled and the pumps stopped, water came into the sub-basement to the height of four feet in a very few hours. After re-excavation and due examination it was found that the defects existed where the seals had been made at the footings, due to the materials not bonding satisfactorily.

The work was then done over with thoroughly saturated felt of the lightest weight that it was possible to obtain. At the present time the sub-basement, which is thirty feet under ground, is absolutely water-tight.

Another factor of importance is that the men employed in work of this kind should be thoroughly familiar with it, should be regularly engaged in jobs of this sort and thoroughly understand every detail involved. It is a common practice to permit any kind of ordinary labor to apply waterproofing material under inspectors who have not had experience to warrant their judging anything other than the quantity of materials used. The services of a practical waterproofing man are necessary. Furthermore, he should be concerned solely with the results desired on a given job and not employed in advocating any particular brand or grade of materials. He is then able to devote unbiased judgment and valuable experience to the task in hand.

Mr. Wagner. MR. WAGNER (*Author's closure by letter*).—Mr. Forrest raises some very interesting points. The terms "asphalt" and "coal tar" are entirely too general and there should certainly be some agreement between experts in this line as to what the proper names should be. There are a great variety of materials which resemble each other very closely, but which have very different properties.

The writer is not an advocate of asphalt mastic, at least for waterproofing floors for railroad bridges, although he has been associated with its use where no other method seemed prac-

Mr. Wagner.

ticable, and where the results have been better than might have been expected. He does believe that it is one of the best and most durable methods that can be used for waterproofing masonry where there is no vibration, provided proper materials are used. His experience has been entirely with mastics made from imported natural rock asphalts. Recently the waterproofing of a railroad arch over a street in Philadelphia was examined after having been in use for twenty-one years. The arch was stone faced and filled with brick, plastered on top with cement mortar and covered with an asphalt mastic made from Val de Travers natural rock mastic, 1 in. in thickness. The dry stone packing was placed directly on top of the waterproofing, and although it had cut down into the mastic at many points, there seemed to be always a sufficient amount remaining to answer the purpose. The top surface of the mastic was as bright as the day it was laid, and showed no signs of disintegration, and the fracture was such as to indicate that it was good for many more years.

In the paper the writer called attention to only two kinds of waterproofing, or rather to only two conditions, and it does seem to him that it should be possible to have proper specifications for these two conditions.

Take the single case of a solid-floor railroad bridge. It is believed that a waterproofing material is required which combines ductility with adhesiveness, and which has these properties under all atmospheric conditions. Experience has shown that if the materials to be waterproofed in a bridge floor, whether some agreement between experts in this line as to what the proper steel or concrete, are *clean and dry*, it is possible to have practically perfect adhesiveness, and that if the material in the waterproofing is ductile at low temperatures and will not run at high temperatures, good work can be done. There are asphalts which will give these results, but the writer has not as yet been able to find them among the coar-tar products. He is glad to hear, however, that coal-tar pitch has the property of self-healing, as experience indicates that this property is necessary when waterproofing is subject to vibration at low temperatures. Would not such a structure be liable to leak if the material fractures at a low temperature, and water is applied before the

Mr. Wagner. temperature rises to such a point that the self-healing can take place?

Investigations made with a large number of asphaltic materials show that they are subject to great variation with respect to their ductility, some of them having this property only at temperatures of about 70° F. and over, being brittle at about freezing temperatures. How long such asphalts will retain their ductility is an interesting question. Some of them have been carefully watched for about four years, and do not seem to have changed in that time.

It is very important that there should be uniformity in structural materials, and tests should be made of every shipment. On work with which the writer has been connected careful tests have been made on the waterproofing materials used in order to determine this property, and thus ascertain a proper basis for specifications. So far the results have shown that it is possible to obtain as much uniformity in asphalts as in materials of any other class. It is hoped that experience in the future will finally result in specifications for waterproofing materials for solid-floor bridges, which can be met commercially, and at the same time ensure a material which will be durable and meet the demands of the conditions.

TESTING OF REFRACTORIES.[1]

By A. V. Bleininger.

The subject of testing refractories is in a somewhat unsatisfactory condition, both from the standpoint of the consumer and the producer. This is not surprising, owing to the fact that these materials differ widely in composition and are used under greatly varying conditions. The subject has not been mastered as thoroughly as its importance deserves, as is evidenced by the many erroneous and misleading statements contained in books on metallurgy. It would seem desirable, therefore, that refractories be studied more exhaustively than has been done in the past.

Neglecting the subject of special refractories, the three classes of materials generally employed may be roughly grouped into clay, silica, magnesia and alumina refractories. The classification into neutral, acid, and basic materials cannot be justified owing to the indefiniteness of the term "neutral" and since many clay refractories are far from being neutral in their behavior towards slag. Again, while both the magnesia and alumina products might be included under basic materials they differ widely in their effect upon slags. It would seem more desirable, therefore, to adhere to the terms which at once indicate the composition of the materials.

In use, refractories are called upon to stand up under many conditions. They may be expected to resist high temperatures under negligible or under considerable loads, to resist abrasion at various temperatures, to prevent the intrusion of slags, glass, carbon or metallic vapors, to withstand sudden temperature changes, the effect of superheated steam, sulphurous or other gases, and other special conditions. It is manifestly impossible to expect that a single refractory will fulfil all of these functions with any degree of satisfaction. There are, however, certain requirements of characteristic importance which impart to

[1] By permission of the Director, Bureau of Standards.

refractories their greatest value and of these refractoriness is obviously the most prominent. The lower the desired working temperature is for a certain material the easier it may be adapted to any particular requirement. From this it follows that the greatest difficulty is encountered in obtaining products of high heat-resisting power, which at the same time possess some of the special requirements demanded. A valuation of these materials on the basis of their refractoriness would thus seem to be a fair procedure.

FUSION TESTS.

Unfortunately, the term "refractoriness" has no specific meaning. Generally, it is supposed to represent the so-called melting point of a material. This confronts us with a serious difficulty due to the fact that the substances used for work of this kind possess no melting point in their proper physical conception. It is a well-known fact that silicates, like clays, lacking in well-defined crystalline structure and of high molecular viscosity, offer no definite transition point from the solid to the liquid phase, nor any other criterion, corresponding to the transformation of a substance from the anisotropic to the isotropic state. We are compelled therefore to depend upon deformation data, such as the rounding of edges, the bending of specimens of standard size and shape in the manner of Seger cones, or the formation of drops. But even when a standard condition of deformation has been established it is evident from theoretical considerations that the rate of heating will have a decided influence upon the deformation temperature, rapid firing resulting in a higher point than that from a slower rate of heating. This condition is made still more complicated by the heterogeneous nature of the materials to be tested, which consist of particles of different substances varying greatly in size. It is thus seen that the determination of the softening temperature is not as simple as it might appear, and that in the comparison of refractories a standard mode of procedure should be established. Fortunately, the higher the temperature involved, the less marked seems to be the influence of the rate of heating upon the deformation point.

In making a softening-point determination of a refractory it seems desirable to grind the specimen so that the material

will pass the 80-mesh screen and to make up small tetrahedra of the size of the higher pyrometric cones. It is hardly necessary to point out that any metallic iron introduced by grinding should be removed by means of a magnet. The furnace to be used should be a carbon-resistance furnace of the type shown in Fig. 1, or still better, one heated by means of a coil of molybdenum or tungsten wire in an atmosphere of hydrogen. The Arsem

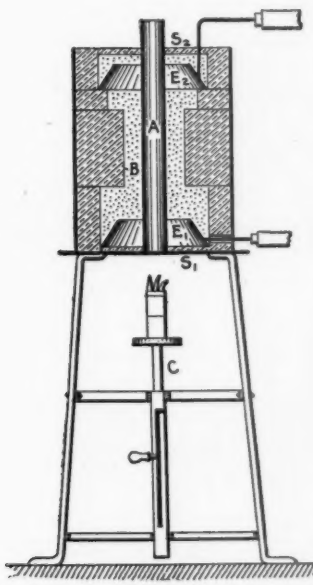


FIG. 1.—Electric Carbon-Resistance Furnace for the Determination of Softening Temperatures.

vacuum furnace has been used very successfully by Doctor Kanolt in work of this kind. The crucibles or tubes used as receptacles for the specimens may consist of an alundum, or, for very high temperatures, of a fused magnesia body. It has been the experience of the writer that somewhat impure magnesia containing from 5 to 10 per cent of ferric oxide, silica and alumina, is to be preferred to the pure substance for this purpose.

The deformation points to be noted are the rounding of the

tip of the cone and the bending of the latter as prescribed for all pyroscopes of this kind. The temperature of these points is most readily estimated by means of standard cones,[1] the deformation points of which should be fixed as closely as possible by means of an optical pyrometer, preferably of the Morse type. The specimen of refractory to be tested should be surrounded by a number of the standard cones and its appearance compared with that of the latter. Wherever possible, the direct estimation of the temperature is, of course, preferable.

LOAD TEST.

While for general comparison, the determination of the deformation point is very desirable and may be used as a

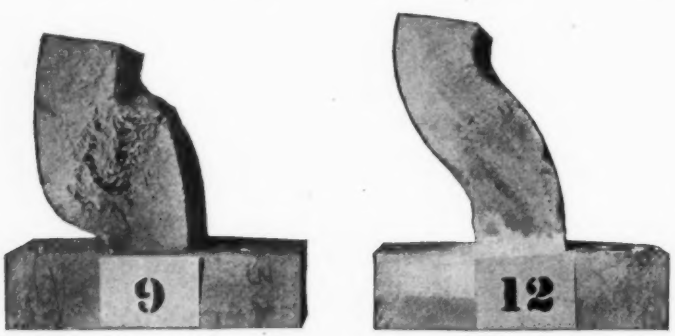


FIG. 2.—Specimens of Fire Brick which have Failed in the Load Test.

criterion of the value of the refractory, it is by no means an accurate index of its behavior in use. Thus, a good many so-called No. 2 fire clays will show quite high deformation temperatures corresponding to, say, cone No. 31, and yet fail under practical heat conditions. To a large extent this must be ascribed to the high viscosity of the materials, which causes them to deform but slowly, and their heterogeneous structure.

In order to overcome this condition it has been suggested to subject the refractories to load conditions at an average furnace temperature,[2] in which the compression of the specimen is only a small fraction of its crushing load at atmospheric

[1] Obtainable from Prof. Edward Orton, Jr., Columbus, Ohio.

[2] *Technologic Bulletin No. 7*, Bureau of Standards, Washington, D. C.

temperatures. In this test the material is usually represented by a brick of standard size placed on end and heated at a prescribed rate up to 1350° C., which temperature is maintained constant for one hour. The load is 50 lb. per sq. in. The viscosity effect of the material, by virtue of which it is barely capable of sustaining its own weight at the higher temperatures, is overcome by this procedure, and in a measure the refractoriness is estimated, since failure occurs practically always through the softening and the deformation of the mass, as illustrated by the photographs shown in Fig. 2. At the same time the product is tested as a whole in the condition in which it is used, so that the result takes into account the physical structure and other factors and represents, besides, the actual standing-up quality under load conditions. This latter information is very desirable for many uses where the factor of load is involved, as for gas benches, arches, crowns, retorts, glass pots, etc.

VOLUME CHANGES.

A very important consideration regarding refractories is their change in volume upon heating in actual use, not considering that due to the thermal coefficient of expansion. Many materials of this kind are subject to positive or negative volume changes. These may be continued contraction, caused by insufficient firing in the process of manufacture, or the formation of glass from the several anisotropic constituents, the dissociation of clay into sillimanite, the transformation of quartz into tridymite and cristobalite, and other more or less unknown chemical and physical changes. This whole matter is one of considerable practical importance, since the irregular behavior of the materials in this respect may mean their failure in use. There is a somewhat general tendency to underburn refractories, which needs correction. The claim made by some that fire bricks need not be burnt in kilns to the maximum temperature possible is fallacious in every case. For this reason the iron discolorations appearing on hard-burnt brick are an indication of good burning, and it is unwise to object to such products on the ground of their external appearance.

The question of volume changes is most readily investigated by reburning the product several times to temperatures not

lower than 1350° C. and noting the differences in volume by means of the Seger volumenometer, using as a check the determinations of the apparent and true specific gravity, the latter to be determined on the crushed material passing the 80-mesh sieve. At the same time there is need of much work concerning the thermal coefficient of expansion and other volume changes observed by linear measurements made upon specimens heated in appropriate furnaces.

RESISTANCE TO SUDDEN TEMPERATURE CHANGES.

The resistance of refractories to sudden temperature changes offers an important problem of great practical interest. In a number of laboratories such determinations are already being made by quenching, in cold water, bricks heated to redness, and noting the number of quenchings required to destroy the brick. In the practice of the Bureau of Standards laboratory, however, it has been noted that this test, in spite of its apparent severity, is not as discriminating as the cooling of heated bricks on one side in a stream of cold air. In the latter test more severe strains are set up and the resisting qualities are more clearly brought out than in the quenching. It goes without saying that the conditions of the test should be made as strictly comparative as they can be made with reference to the heating, the air pressure, length of treatment, etc.

RESISTANCE TO SLAGGING ACTION.

Regarding the resistance of refractories to the action of slags it has been suggested by the Laboratory of the Tonindustrie Zeitung, Berlin, that cubes be made of the material to be tested, containing a depression, which is to be filled with the type of slag or glass under consideration. These are then carried in a furnace to a temperature sufficiently high to bring about fusion of the fluxing silicate. After cooling, the cubes are broken and their fracture studied. This procedure no doubt could be developed into a very instructive test which would be helpful to the manufacturer in developing the best conditions for resisting slag intrusion.

CHEMICAL COMPOSITION.

In work with refractories it is very desirable to know the chemical composition of the materials to be examined, even though the physical tests are of more direct importance. If all of these products were physically homogeneous the chemical composition would be of the greatest significance. It is obvious that the so-called impurities differ according to the type of the refractory. While in clay and siliceous materials the fluxes comprise the basic constituents, iron oxide, lime, magnesia, potash and soda, in magnesite brick the silica, alumina and ferric oxide must be considered detrimental.

In comparing the composition of many refractories, especially fire-clay products where there are about eight constituents to be considered, it is advisable to make use of empirical chemical formula in which the constituents of the same class are grouped together. By the artifice of making one constituent equal to unity it is possible to reduce the variables to two expressions. Thus, from the following fire-brick analysis, the formula given below may be computed:

Silica	65.34	per cent.
Alumina	30.01	"
Ferric oxide	1.45	"
Lime	0.18	"
Magnesia	0.52	"
Soda	0.38	"
Potash	1.21	"

$$0.061\ FeO,\ 0.011\ CaO,\ 0.044\ MgO,\ 0.021\ Na_2O,\ 0.044\ K_2O,\ 1\ Al_2O_3,\ 3.693\ SiO_2.$$

This empirical formula is simplified by combining the fluxing constituents so that the final expression becomes $0.181RO$, $1\ Al_2O_3$, $3.693\ SiO_2$, containing but two variables. The slight trouble involved in this calculation is amply repaid by the ease with which the chemical characteristics of the material may be summarized. Referring to fire clays, by comparing the resulting formula with that for pure dehydrated clay substance, $Al_2O_3 \cdot 2SiO_2$, the silica in excess is at once noted. Similarly, the total fluxes expressed in molecular equivalents give an excellent index as to the amount of impurities and their joint effect,

especially in connection with the silica content, since it must be realized that the basic constituents are the more potent, the more siliceous the clay is. The practice of estimating the refractory value of a fire clay by adding the percentages of the fluxes, is quite misleading and is apt to lead to erroneous conclusions, since evidently the resultant effect is more apt to be proportional to the molecular amounts than to the simple weight relations.

SUPPLEMENTARY STUDIES.

Further study is needed also of the specific heat and the

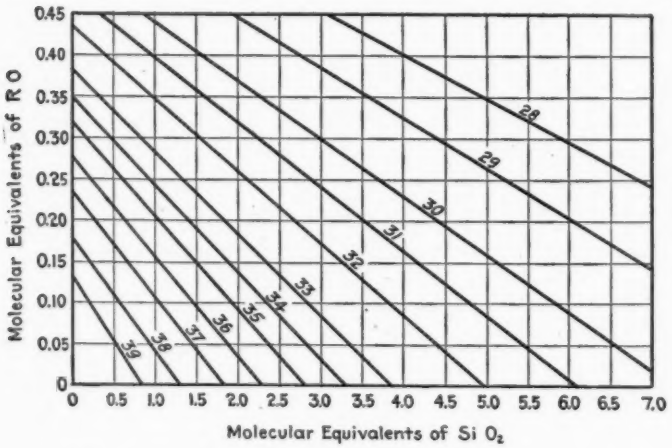


FIG. 3.—Ludwig's Diagram Correlating the Chemical Composition with the Refractoriness of Fire Clay.

thermal conductivity of refractories, although such work as that of Wologdine and others has thrown considerable light upon the latter as applied to clay refractories.

In the discussion of the subject, the question of the mortar used in laying up refractory products is a vital one, and it might be stated that in each case the quality of the cementing materials should be equal to that of the bricks used.

In the following paragraphs some of the more important facts concerning the various grades of refractories are collected.

Clay Refractories.—The greatest heat resistance is shown

by the purest clays, approaching the kaolin composition which corresponds to a composition of 53.8 per cent silica and 46.2 per cent alumina in the dehydrated state. Any increase in silica reduces the refractoriness, reaching a minimum point about 80 per cent silica and 20 per cent anhydrous kaolin. The softening temperature of the pure clay substance is about 1740° C. and that of the kaolin-silica minimum 1600°. The fluxes, comprising the basic oxide and titanium oxide, lower the refractoriness very rapidly. Doctor Ludwig, in determining the softening

TABLE I.

Cone No.	Formula of Silicate Mixture.	Softening Temperatures, deg. Cent.	
		Given by Makers.	From corrected data, by Kanolt.
26	$\left.\begin{matrix}0.3\ K_2O \\ 0.7\ CaO\end{matrix}\right\}$ 7.2 Al_2O_3 . 72 SiO_2	1580	1600
27	$\left.\begin{matrix}0.3\ K_2O \\ 0.7\ CaO\end{matrix}\right\}$ 20 Al_2O_3 . 200 SiO_2	1610	1620
28	Al_2O_3 . 10 SiO_2	1630	1635
29	Al_2O_3 . 8 SiO_2	1650	1650
30	Al_2O_3 . 6 SiO_2	1670	1670
31	Al_2O_3 . 5 SiO_2	1690	1685
32	Al_2O_3 . 4 SiO_2	1710	1705
33	Al_2O_3 . 3 SiO_2	1730	1720
34	Al_2O_3 . 2.5 SiO_2	1750	1740
35	Al_2O_3 . 2 SiO_2	1770	1755

temperatures of a large number of German fire clays, correlated these with the chemical composition as represented by the formula $aRO \cdot Al_2O_3 \cdot bSiO_2$. These results are presented in the diagram of Fig. 3.

For the sake of correlating the cone numbers with the approximate fusion temperatures, Table I is given for Nos. 26 to 35, inclusive.

From the isothermal lines of Ludwig's diagram it is observed that the effect of the fluxes becomes more potent as the proportion of silica increases. The results, however, cannot be

applied directly without keeping in mind the fact that the lack of physical homogeneity will tend to displace the softening temperatures to a greater or less extent.

Doctor Kanolt[1] in his careful investigation of the melting point of American fire brick found this temperature to vary between 1555° and 1725° C. The mean of the melting points of 41 samples of fire clay bricks was 1649° C. From the experience gained in the testing of many brands of fire brick it would seem

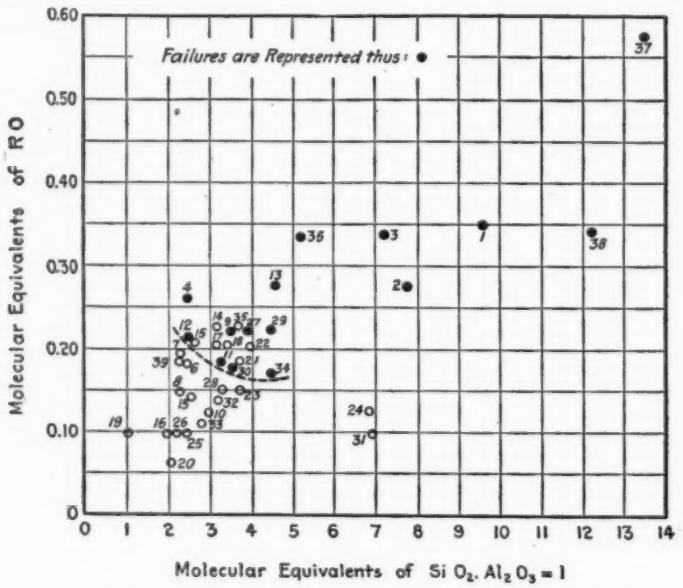


FIG. 4.—Diagram Correlating the Content of Fluxes and of Silica in Fire Brick with the Load-Test Behavior.

that no material of this kind may be called of good grade unless it shows a softening temperature above 1670° C.

The behavior of these bricks under load conditions (50 lb. per sq. in. at 1350° C.), correlated with the chemical composition is shown in the diagram of Fig. 4. Failure was considered to have taken place when the specimens showed marked deformation or contracted more than 1 in., referred to the standard

[1] *Technologic Bulletin No. 10*, Bureau of Standards.

length of 9 in. It was found that a content of more than 0.22 equivalent of fluxes is apt to result in failure in the load test with a silica content varying up to $1Al_2O_3 \cdot 3SiO_2$. With a higher content of silica the permissible RO decreases. Thus with 4.4 molecular equivalents of silica an RO content of 0.17 may bring about failure.

Other properties, such as the resistance to sudden heating and cooling, must necessarily depend to a large extent upon the physical structure and very little data are available for the discussion of this topic.

The thermal coefficient of expansion of the various fire clay refractories likewise has not been studied in any extensive way and the constants available are meager and to some degree unreliable.

The heat conductivity of these products has received more attention and the best-known work referring to this point is that of Wologdine, who found this constant to vary from 0.0025 to 0.0045, referred to gram-calories per square centimeter and through a thickness of 1 cm. for a temperature difference of 1° C. Generalizing, it may be said that the thermal conductivity varies inversely as the porosity.

The specific heat of raw fire clay was found by Knote[1] to be 0.237 and of the burnt clay 0.200. No information is available as regards the variation of this constant for different clays and bodies with temperature.

Since it should be the invariable rule to burn all refractories to as high a temperature as possible in the kilns, the contraction upon refiring to, say, 1350° C., should be as small as possible and should in no case exceed 1 per cent for high-grade clay refractories.

Silica Refractories.—According to Doctor Kanolt the deformation point of pure silica is 1750° C., while that of silica brick was found to be about 1700°. The great value of these products in their industrial use is due to the rigidity of structure at permissible furnace temperatures. The decrease in viscosity does not take place over such a long interval as in clay and hence softening under load conditions is not so much to be feared.

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[1] *Transactions*, Am. Ceramic Soc., Vol. 14, p. 395.

Failure takes place close to the softening temperature of the material. Silica brick, however, are more subject to spalling due to sudden temperature changes and cannot resist mechanical abrasion as well.

The most significant phenomenon connected with the use of silica bricks is their expansion upon further heating due to molecular changes, the formation of cristobalite, tridymite and glassy matrix. The mechanism of these transformations is not yet understood fully, nor the effect of the initial crystalline state upon the subsequent volume changes. Upon calcining silica rock repeatedly, great variations are found in regard to the expansion of the material; in some cases the maximum increase in volume is obtained after the first heating, while in others each subsequent firing causes persistently a steady increase. Cramer[1] in refiring silica bricks of various brands in the porcelain kiln found that most brands ceased to expand after the third firing.

Some discrepancy of opinion exists also in regard to the difference in behavior between silica brick containing clay or lime as a binder. The general preference at the present time seems to be for the latter, at least as far as American practice is concerned. Chemical analysis is useful in estimating the impurities of silica brick, principally lime and iron.

In testing silica brick under load conditions, 50 lb. per sq. in., at the Pittsburgh Laboratory of the Bureau of Standards, no deformation or contraction was noted at 1350° C. nor at 1470° C., thus illustrating the excellent standing-up quality of this material. The thermal conductivity of silica brick was found by Wologdine to vary from 0.0020 to 0.0031.

Magnesite Refractories.—These products, manufactured by calcining the crude mineral to a high temperature, crushing, briquetting and firing the resulting shapes at as high a heat as possible, in the nature of the case, are basic and very refractory. Kanolt found the melting point of magnesite brick to be 2165° C. Like silica bricks, these refractories are sensitive to temperature changes and cannot resist mechanical abrasion very satisfactorily. For many purposes the magnesite products are indispensable. When properly calcined and burned, very little

[1] Handbuch der gesammten Tonwarenindustrie, p. 895.

shrinkage is found to take place in use. Pure magnesite is not desirable for this purpose owing to the difficulty in producing products of constant volume, and a certain amount of iron oxide, silica and alumina seems necessary for this purpose. The most desirable compositions for the various purposes have not been worked out. The manufacturer is to a large extent dependent upon the composition of the raw material and chemical control is difficult under the circumstances.

In the load test (50 lb. per sq. in.) a magnesite brick was found to fail rather suddenly at 1550° C. It seems then that initial softening must take place at this temperature. Fused magnesia is at the present time being introduced as a special refractory for certain purposes. The thermal conductivity of magnesite products is considerably higher than that of the other refractories under discussion. Wologdine gives values varying from 0.0058 to 0.0071.

Alumina Refractories.—Pure alumina melts at 2010° C. (Kanolt). Refractories of this type, being made usually of a mixture of bauxite and fire clay, for this reason must fuse at considerably lower temperatures. Kanolt found the melting point of such products to vary from 1565° to 1760° C. This indicates no appreciable gain in refractoriness over the best fire-clay materials. Bauxite was found by this investigator to fuse at 1820° C. and bauxite clay at 1795° C. The thermal conductivity was found to be, according to Wologdine, about 0.0032.

The addition of alumina to fire clay increases the refractoriness of the latter. Upon continuing the increase in alumina the fusion temperature of sillimanite ($Al_2O_3 \cdot SiO_2$) is reached, 1810° C., and finally the melting point of alumina, about 2010° C., modified, of course, by the presence of fluxes like iron oxide, lime, magnesia and the alkalies.

One objection to bauxite brick has been the continued shrinking of the material, caused by insufficient calcination of the bauxite. Of late bauxite or alumina fused in the electric furnace has been applied in this connection in the manufacture of high-grade special refractories. The coefficient of expansion of a fused alumina (alundum) body, between 100° and 900° C., was found[1] to be 866×10^{-8}.

[1] *Transactions*, Am. Ceramic Soc., Vol. 14, p. 477.

SPECIFICATIONS.

Some attempts have been made to work out specifications governing clay and siliceous refractories. In the following paragraphs two sets of tentative specifications are quoted, (*a*) those proposed by the English Institute of Gas Engineers, and (*b*) requirements suggested by the Bureau of Standards.

(*a*) SPECIFICATIONS PROPOSED BY THE ENGLISH INSTITUTE OF GAS ENGINEERS.

It is understood that this specification applies generally to material made from fire clay containing approximately not more than 75 per cent silica. It is known, however, that there are in certain areas fire clays containing as much as 80 per cent silica, and material made from such clays shall be considered to conform to this specification if it passes the test herein specified.

1. *Refractoriness.*—Two grades of material are covered by the specification: (*a*) Material which shows no sign of fusion when heated to a temperature of not less than Seger cone No. 30 (about 1670° C.); (*b*) material which shows no sign of fusion when heated to a temperature of not less than Seger cone No. 26. The test shall be carried out in an oxidizing atmosphere, the temperature of the furnace being increased at the rate of about 50° C. per five minutes.

2. *Chemical Analysis.*—A complete chemical analysis of the material is to be provided when required.

3. *Surface and Texture.*—The material shall be evenly burnt throughout and the texture regular, containing no holes or flaws. All surfaces shall be reasonably true and free from flaws or winding.

4. *Contraction or Expansion.*—A test piece when heated to a temperature of Seger cone No. 12 for two hours shall not show more than the following linear contraction or expansion: No. 1 grade, 0.75 per cent; No. 2 grade, 1 per cent.

The test piece shall be 5 or 6 cm. long, the ends being ground flat and the contraction measured by means of vernier calipers reading to 0.1 mm., a suitable mark being made on the test piece so that the calipers may be placed in the same position before and after firing.

5. *Variation from Measurements.*—In the case of ordinary

bricks, 9 by 4½ by 3 or 2½ in. thick, there shall not be more than 1.5 per cent variation, plus or minus, in width or thickness, and in all cases the bricks shall work out their own bond, with not more than ⅛-in. allowance for joint. In the case of special bricks, blocks, or tiles, there shall not be more than 2 per cent variation, plus or minus, from any of the specified dimensions.

6. *Crushing Strength.*—The material shall be capable of withstanding a crushing strain of not less than 1800 lb. per sq. in.

(*b*) SPECIFICATIONS SUGGESTED BY THE BUREAU OF STANDARDS.

In this connection the No. 1 clay refractories are divided into two classes, A and B. The first includes those materials for which both refractoriness and load-carrying ability are required; the second those where refractoriness is demanded but compressive strength at furnace temperatures is not a main requisite. The No. 2 clays are supposed to include those products which are somewhat inferior to the high-grade refractories, but which nevertheless form an important class of products suitable for many uses.

No. 1 A.—Materials of this class should show, when tested in the ordinary manner in the Deville or an electric furnace and heated at a rate so that the final temperature is obtained in not less than one hour, a softening temperature of not less than cone No. 31, approximately 1690° C.

When subjected to the load test at 1350° C. and under a load of 50 lb. per sq. in., a standard fire brick tested on end should show no serious deformation and should not be compressed more than ½ in., referred to the standard length of 9 in.

When tested on end at atmospheric temperature, the compressive strength should not be less than 1000 lb. per sq. in.

The product in its manufacture should not be fired to a temperature lower than that corresponding to cone No. 12, or approximately 1350° C.

Upon chemical analysis the empirical formula calculated from the composition should show a total RO content of not more than 0.22 molecular equivalent, including the iron oxide as FeO.

No. 1 B.—The average softening point of this class of products should correspond to a temperature of not less than cone No. 31, about 1690° C.

In the load test it should show no serious deformation or a contraction of more than $\frac{1}{2}$ in., referred to the standard length of 9 in., at a temperature of 1350° C. and a load of 30 lb. per sq. in.

When tested for compressive strength, on end, at atmospheric temperature, the crushing strength shall not be less than 800 lb. per sq. in.

The product shall not have been fired to a maximum temperature lower than that represented by cone No. 10, about 1300° C.

The chemical formula calculated from the analysis should show a content of RO fluxes of not more than 0.22 equivalent.

One important point has been left unconsidered in these specifications, namely, the question of shrinkage or expansion upon heating fire bricks to higher temperatures. It was thought that the data at hand were insufficient to suggest any requirements.

No. 2.—The softening point of this class of refractories should not be lower than the temperature corresponding to cone No. 28, approximately 1630° C.

In the load test the materials of this classification should be able to carry a load of 25 lb. per sq. in. at 1300° C. without serious deformation or a contraction greater than $\frac{1}{2}$ in., referred to the standard length of 9 in.

The chemical formula, as calculated from the analysis, should not show a content of more than 0.32 equivalent of fluxes.

It is seen from these requirements that the limits drawn are closer than those generally considered for No. 2 fire clays. However, it is believed that with these restrictions this class of refractories would become more generally useful in industrial application.

RELATION BETWEEN THE TESTS FOR THE WEARING QUALITIES OF ROAD-BUILDING ROCKS.

By L. W. Page.

It is generally accepted that the rock in a macadam road is subjected to the influence of three main classes of destructive agencies, and these are mechanical, physical and chemical. Thus the mechanical action of traffic grinds up the rock to powder, which is partially disseminated through the physical agencies, wind and rain. In addition, acids contained in the surface water tend to dissolve out the more solvent mineral constituents, thus aiding in the destruction. Then, too, the expansive action of frost is no inconsiderable factor in the disintegration of the wearing surface.

Of the destroying influences, however, the mechanical action of traffic is most severe, and this is a two-fold action. The impact of horses' shoes and wagon wheels fractures the rock, while at the same time it is worn away through abrasion, and, in order to resist rapid destruction, it must possess the properties of hardness and toughness. The hardness of a rock measures its resistance to the displacement of its surface particles by friction, while the toughness is a measure of its resistance to fracture through impact. These two primary requisite qualities are tested in the laboratory of the Office of Public Roads by means of the Dorry hardness test and the impact test for toughness. In addition to these, a third test is employed, namely, the Deval abrasion test. The impact test and the abrasion test have both been adopted by this Society.

The Dorry hardness test is performed on a core of solid rock, 25 mm. in diameter, which is held against a revolving cast-steel disk under a pressure of 250 g. per sq. cm. (See Fig. 1.) Standard crushed quartz, sized between 30 and 40-mesh screens, is fed upon the revolving disk. The specimen with its containing device is weighed before the test and again after the cast-steel disk has turned through 1000 revolutions. The loss in weight

is an index of the hardness of the specimen, and in order to make the results approximate those of the Deval abrasion test, the hardness coefficient is calculated by subtracting one-third of the loss in weight from the constant, 20.

The impact test is made on carefully prepared cylinders, 25 mm. high and 25 mm. in diameter, cut from the solid rock.

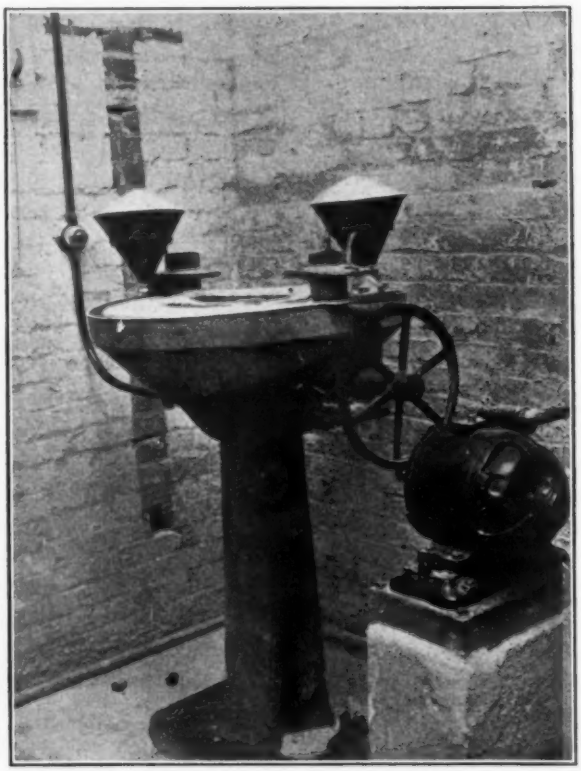


FIG. 1.—Dorry Hardness Machine.

A weight of 2 kg. is allowed to fall upon a spherical-ended plunger weighing 1 kg., resting in contact with the specimen. The height of the first blow is 1 cm. and each successive blow thereafter is increased in height by 1 cm. until the specimen ruptures. (See Fig. 2.)

The Deval abrasion machine (see Fig. 3) consists of cylinders 20 cm. in diameter by 34 cm. long, mounted at an angle of 30 degrees with the horizontal. The specimen consists of as nearly as possible 50 pieces of broken rock weighing 5 kg. After revolving the cylinders 10,000 times, the amount of material finer than $\frac{1}{16}$ in. is obtained and the percentage of wear is calculated



FIG. 2.—Page Impact Machine.

on this basis. The French coefficient of wear is likewise used in reporting results and is calculated by dividing 40 by the percentage of wear.

Since the road-material testing laboratory was established in the United States Department of Agriculture in 1900, several thousands of tests have been made on samples of rock sub-

mitted from various parts of this country and from foreign countries, and the test records furnish abundant opportunity for comparing the wearing qualities of different kinds of rocks with one another, and for determining the relative values of the several tests for estimating the wearing values of road-building materials.

RELATION BETWEEN THE DORRY HARDNESS TEST AND THE AUTHOR'S STANDARD IMPACT TEST.

The relation between the qualities of hardness and toughness is best seen by reference to Fig. 4, on which are plotted

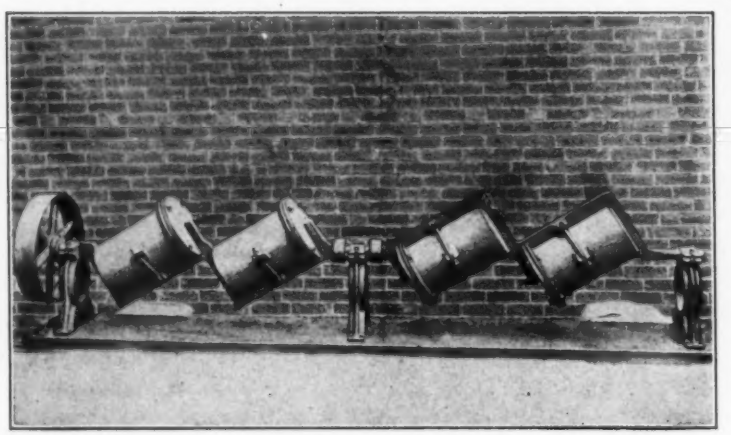


FIG. 3.—Deval Abrasion Machine.

the results obtained from the tests of 1538 samples of different kinds of rocks. The Dorry hardness coefficients are plotted as ordinates and the values for toughness as abscissas. The results are plotted using all of the tests performed up to January 1, 1911. The individual results for hardness are averaged for the different values of toughness and the averages are shown in large circles, which are the gravity centers of the small circles. The solid line very closely approaches the points marked by the large circles.

Reference to the plotted points will show a very definite relationship between the properties of hardness and toughness.

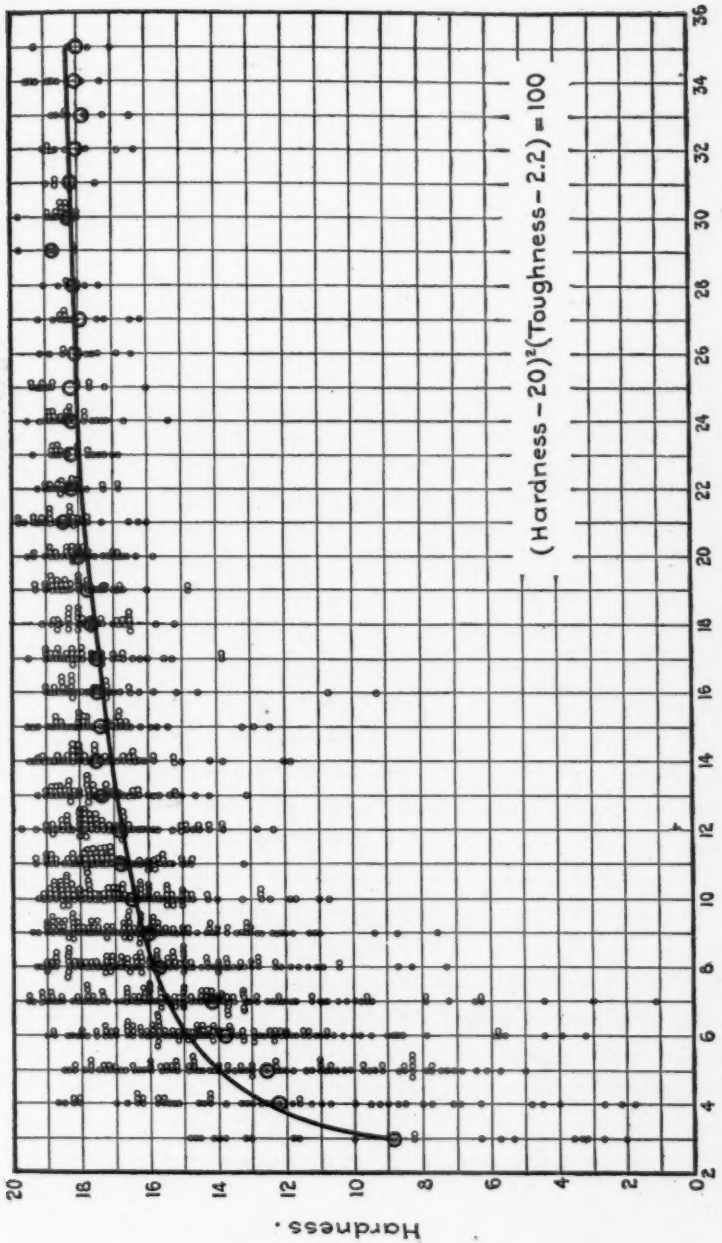


FIG. 4.—Relation between Hardness (Dorry Hardness Test) and Toughness (Page Impact Test).

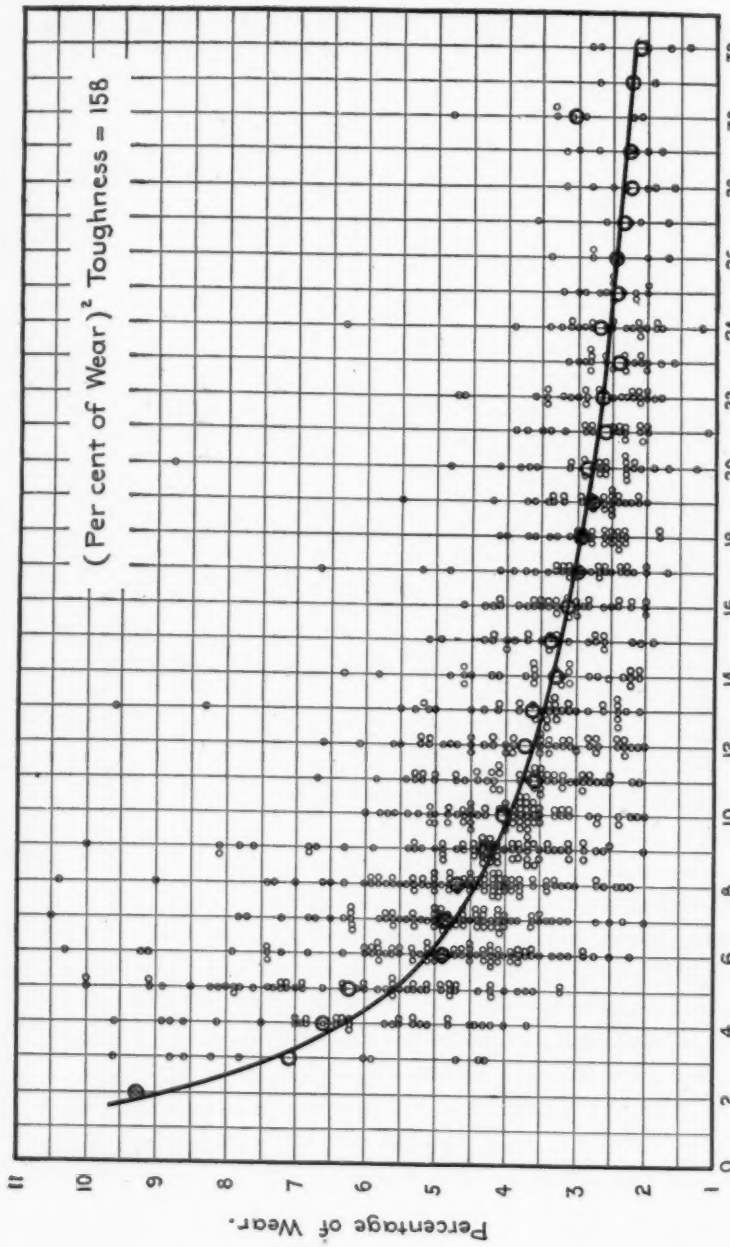


FIG. 5.—Relation between Percentage of Wear (Deval Abrasion Test) and Toughness (Page Impact Test).

It will be seen that as the toughness of a rock increases the hardness likewise increases, with the increase in hardness occurring at a rapid rate for low values of toughness and very slowly for the higher values of toughness. When the toughness is low, a very considerable deviation of the individual from the average hardness results will be noted. On the other hand, when the toughness is high, the individual results for hardness more nearly approximate the average results. A very important fact to be noticed is that when the toughness is high, the hardness is invariably quite high. On the other hand, when the toughness is low, the hardness may be either high or low. It would seem, then, that although high hardness invariably accompanies high toughness, high toughness does not necessarily accompany high hardness. Another important point to be noticed is the fact that when a rock has an average value for toughness, its hardness is likely to be of average value or at least it will not be of unduly low magnitude. From a consideration of these facts, it is apparent that a toughness test might be used for a quick determination of the road-building qualities of a rock to the exclusion of the hardness test, although the reverse is not true, since it is possible for a rock to have very high hardness and at the same time be of extremely low toughness.

The relation between average hardness and toughness may be expressed mathematically as follows:

$$(\text{Hardness} - 20)^2 \times (\text{Toughness} - 2.2) = 100$$

or

$$\text{Hardness} = 20 - \frac{10}{(\text{Toughness} - 2.2)^{\frac{1}{2}}}$$

This equation expresses quite accurately the relation between the average values for hardness and toughness, but for low values of toughness it has no usefulness because of the wide deviation of the individual from the average results. However, for high toughness values, the hardness of a rock may be calculated with reasonable certainty, knowing the toughness. The assumption that a rock having infinite toughness will have the highest possible hardness coefficient (20) was used in deriving the above equation. This seems to be a reasonable assumption in view of the tendency of the hard-

ness to increase with increasing toughness. The equation was likewise made to satisfy the average ordinates on the curve.

RELATION BETWEEN THE DEVAL ABRASION TEST AND THE AUTHOR'S STANDARD IMPACT TEST.

The relation between percentage of wear and toughness is plotted in Fig. 5, with the percentages of wear plotted as ordinates and the toughness values as abscissas. As in the previous curve, the ordinates are averaged, and the average values are plotted in large circles. In general, it will be noticed that the percentage of wear decreases as the toughness increases, at a rapid rate for low values of toughness, and slowly for high values of toughness. The relation between the average values of hardness and toughness may be expressed as follows:

$$(\text{Percentage of Wear})^2 \times \text{Toughness} = 158.$$

The individual results for percentage of wear deviate considerably from the average results for low values of toughness. For high values, however, the deviation is not so serious. A rock with high toughness almost always has low values for percentage of wear, whereas a rock of low toughness may be either high or low in percentage of wear. The above relation, therefore, might be used to estimate approximately the percentage of wear of a rock when the value of the toughness is known, provided the toughness is high. It is impossible, however, to calculate the toughness when the percentage of wear is known. This equation was derived under the assumption that a rock of infinite toughness would have zero for a percentage of wear, and that a rock of zero toughness would have a high percentage of wear. At the same time the equation was made to satisfy the average of the plotted points.

RELATION BETWEEN THE DEVAL ABRASION TEST AND THE DORRY HARDNESS TEST.

The relation between the percentage of wear and hardness is shown graphically in Fig. 6. It was not considered that a curve of averages would indicate anything of value in view of the wide distribution of the individual results over the plot. A solid line was therefore not drawn through the various points. When the relations already given between hardness and tough-

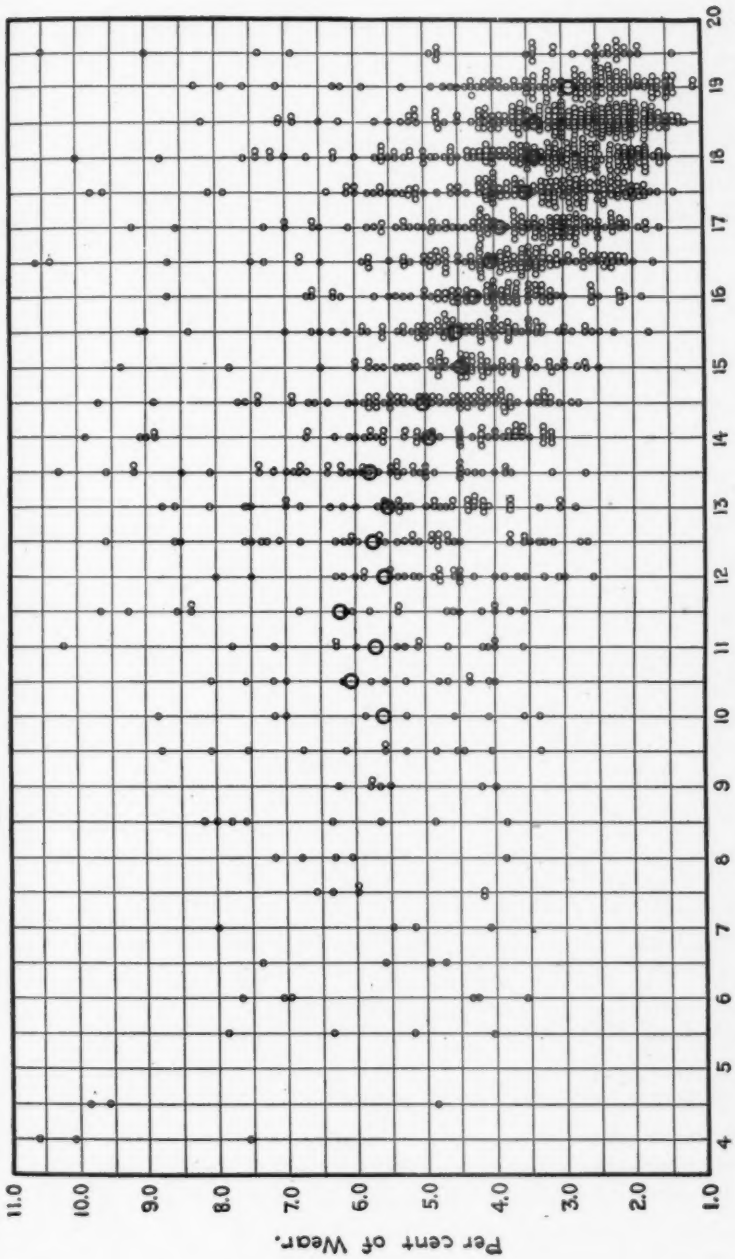


FIG. 6.—Relation between Hardness (Dorry Hardness Test) and Percentage of Wear (Deval Abrasion Test).

ness and the percentage of wear and toughness are combined, there results a relation between percentage of wear and hardness expressed as follows:

$$\text{Percentage of Wear} = \left[\frac{(6320 \times \text{Hardness}) - 63200 - (158 \times \text{Hardness}^2)}{(88 \times \text{Hardness}) - 980 - (2.2 \times \text{Hardness}^2)}\right]^{\frac{1}{2}}$$

This equation expresses quite accurately the relation between the average values for percentage of wear and hardness, but it can be of no practical value in view of the wide deviation of the individual results from the average results. The relation between percentage of wear and hardness does not seem to be as definite as the relations between the percentage of wear and toughness, and hardness and toughness.

A few curves for some of the typical road-building rocks are shown in Fig. 7, Plate XX. These curves are of principal interest in showing the wide deviation that exists in the physical properties of rocks of the same variety. It will be seen that the limestones show the widest deviation from the average curves. Granites are characterized by extremely high hardness with either high or low toughness, while the basalts are hard when the toughness is high and are either hard or soft when the toughness is low.

The above relations, particularly that shown by Fig. 4, seem to indicate that when the toughness of a rock is known, the hardness test is one that might well be omitted, since high hardness in the rocks ordinarily used for road building accompanies high toughness. The wearing qualities of a rock might be determined very definitely either by means of the toughness test or with the Deval abrasion test. The toughness test, in view of the small sample required, is perhaps a cheaper test to perform than the abrasion test. The abrasion test has the somewhat doubtful advantage of requiring the use of larger and better-averaged samples than the toughness test, although even this advantage may be offset by using a sufficient number of specimens in testing toughness. Judging from the foregoing considerations it is the writer's opinion that the prime quality to be determined in a road-building rock is that of toughness. The resistance to wear might also be obtained as very useful information, whereas the hardness test is of least value and might be omitted.

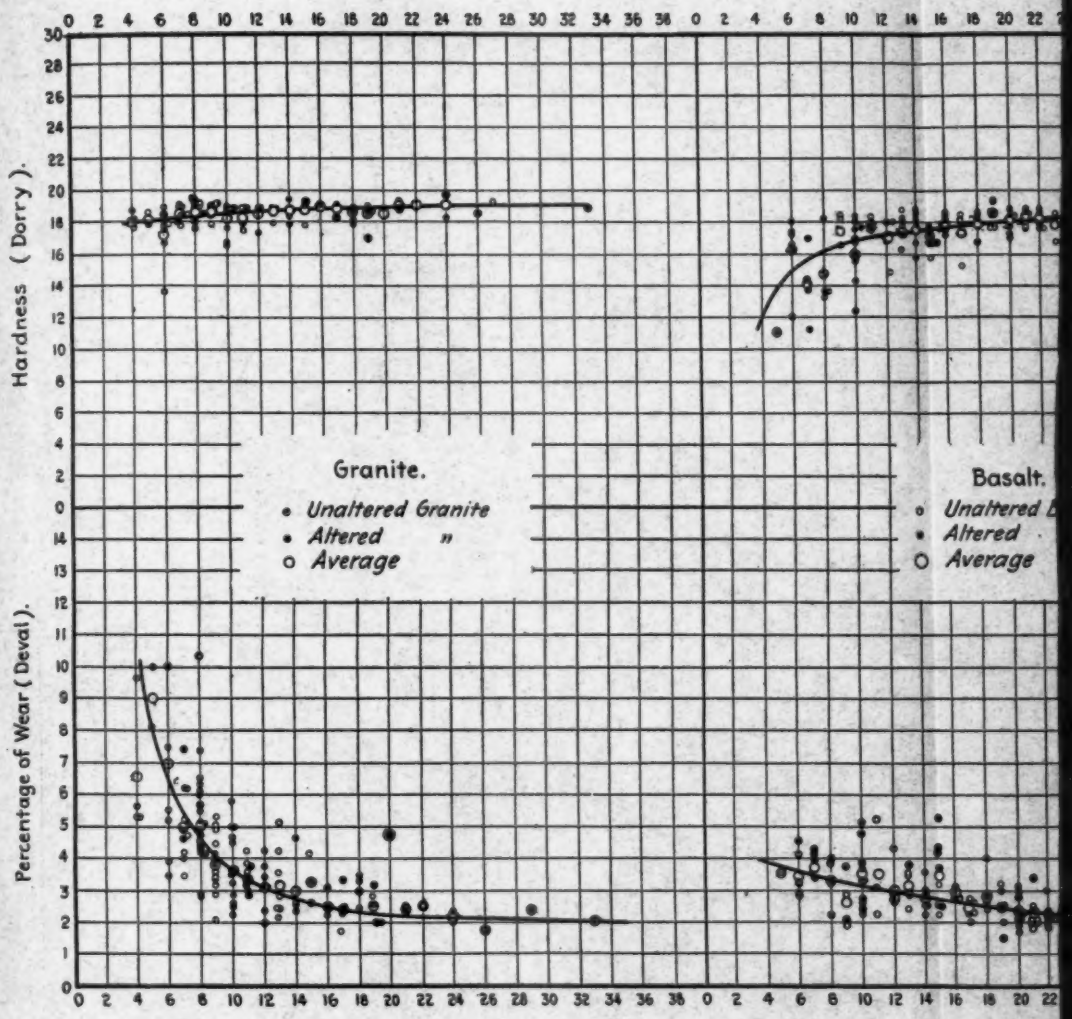


FIG. 7.—Relation between Hardn

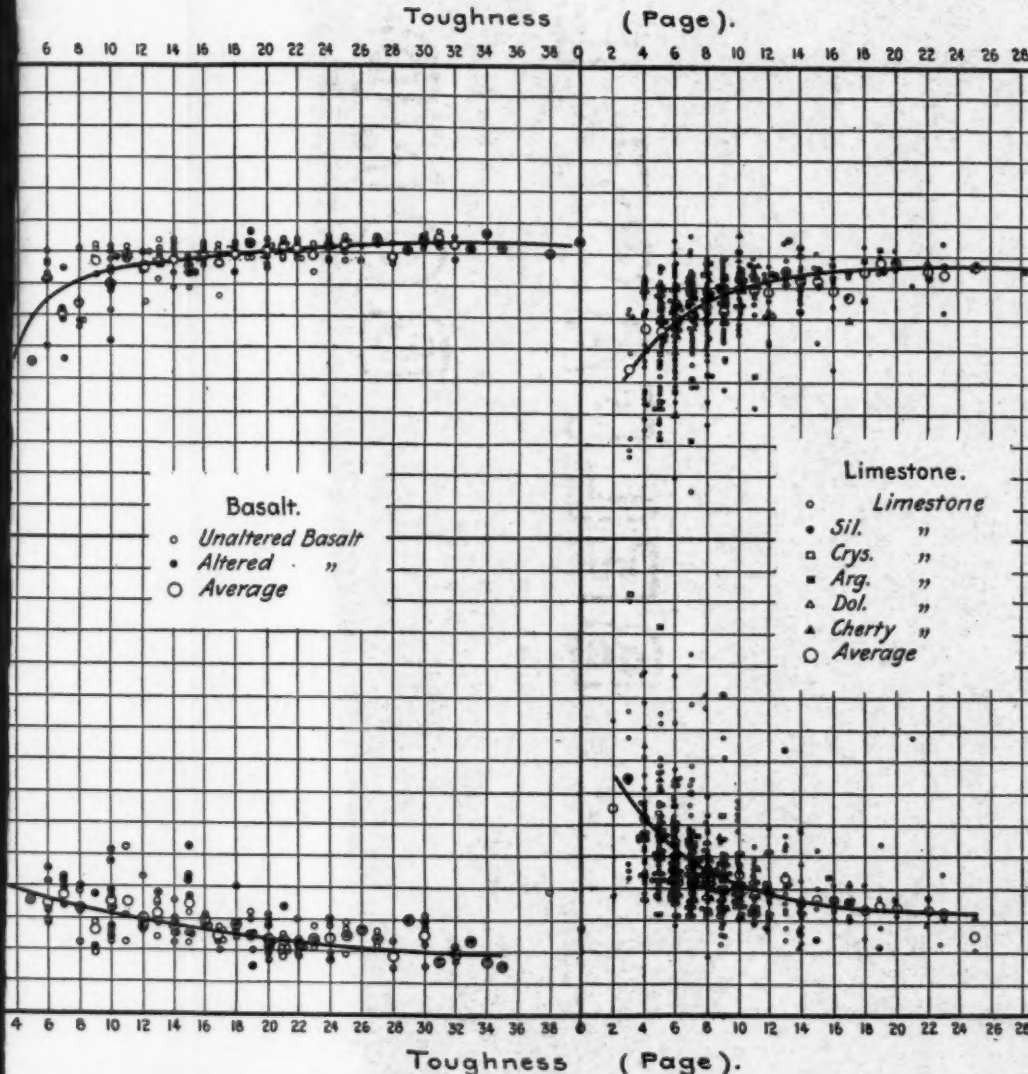
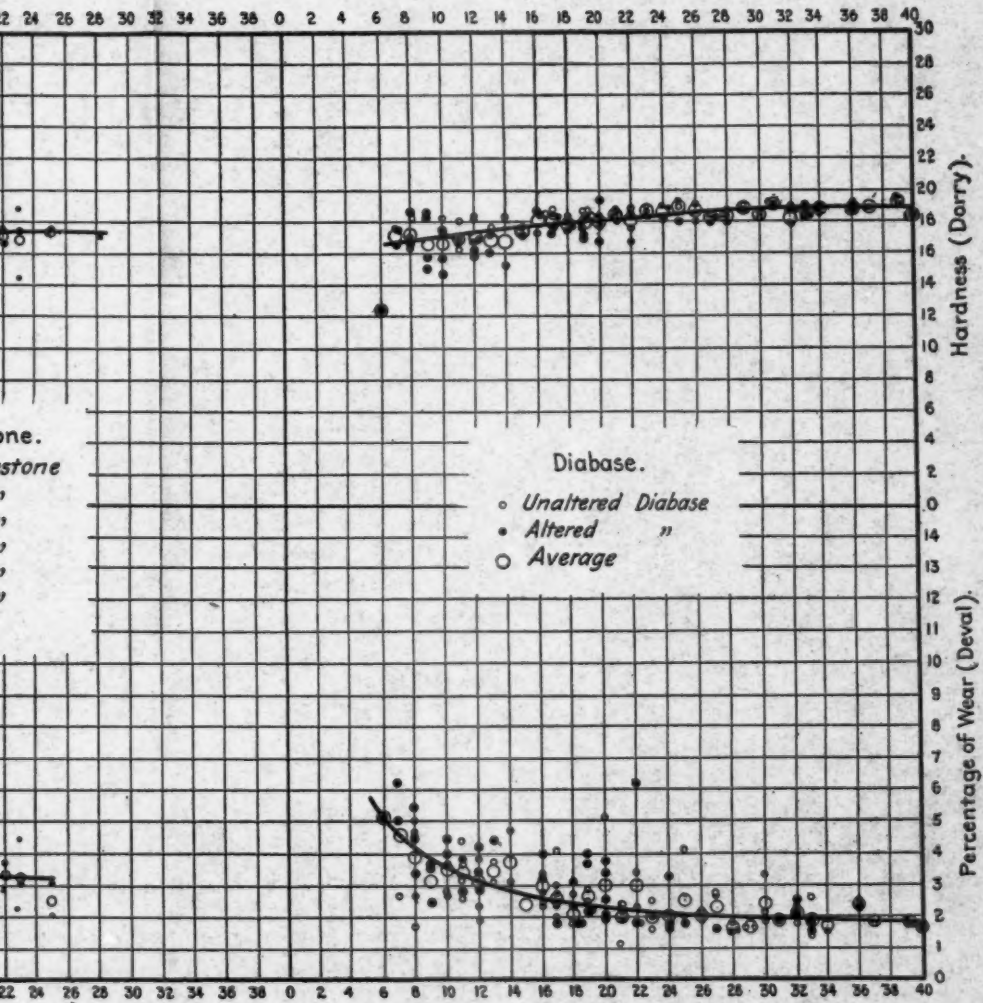


Fig. 7.—Relation between Hardness and Percentage of Wear, and Toughness, for Granite, Basalt, Limes



salt, Limestone and Diabase.

DISCUSSION.

Mr. James Owen.

Mr. Owen.—There is one point relative to the wear of stone roads of different characters which is due to the nature of the fracture of the stone in going through the cracker. A hard stone that breaks off in flakes will stand less wear than a stone of softer texture that will break into cubical form. In the writer's experience all flaky stone, if possible, has been rejected, and cubical stone used where it was convenient, the result showing that such a specification for stone should be a strong factor to be considered in the construction of roads, although it would be rather difficult to make such a laboratory test for fracture.

Another point is arising on which, so far, road builders have not agreed, and that is in the relation between the character of the stone, in the prevalent use of bitumen, and the character of the bitumen. The power of the bitumen will vary with the texture of the stone with the somewhat curious result that the softer the stone the better the bond.

Here arises a third point to be noted, which is that in the use of the close-grouted granite pavement it has been shown that the softer the stone the better the bond of the cement; consequently a better wearing pavement is obtained with a soft granite than with a hard granite.

Mr. L. W. Page.

Mr. L. W. Page.—In reply to Mr. Owen, I might say that the question of the fracture or cleavage of the stone is most important. This is generally most pronounced in crystalline rocks containing mica, and is due to lateral pressure arranging the mica plates all parallel. This is very important.

In regard to the adhesion of bituminous binders to rocks, there has been a good deal of dispute as to whether they adhere best to limestones or to the harder rocks of the trap varieties. It is very hard to get any definite evidence on this point. Take, for instance, manufacturers of asphalt paving blocks: most of them have found that it is best to use the trap rock if they want good resistance to wear and get a binder that will hold

Mr. Page. the trap rock together. It is harder and tougher than the others, and will give longer resistance to wear.

Mr. Boynton. MR. C. W. BOYNTON.—I am not convinced that the results shown by the tests given in this paper will apply to all the types of pavement admitting the use of broken stone as an aggregate. I believe that rocks held together by a permanent binder will behave differently from those held together by an oil or water binder. This conclusion is based upon the results of tests which I have made using the "paving determinator" upon test sections of Portland-cement concrete pavement. This machine which I used in performing these tests upon sections of various classes of pavements, unquestionably accomplishes results more nearly approaching those obtained from natural conditions or agencies than any of the testing methods used before its advent. The experiments referred to showed that granites, which are rocks usually characterized by high hardness and brittleness, possess the best wearing qualities of any aggregates, where Portland cement is used as a binder. Therefore, my deduction is that hardness rather than toughness is the factor exerting the greater influence upon the wearing qualities of this type of pavement. The conclusion seems to follow that Mr. Page's remarks cannot be applied to rocks utilized in all kinds of pavement admitting the use of broken stone.

Mr. Page. MR. PAGE.—I do not believe that Mr. Boynton is right in his assumption that extremely hard rock will give better resistance to wear when held by a Portland-cement binder. It seems to me reasonable to suppose that a semi-plastic bituminous binder will absorb the shocks delivered on a fragment of stone by a blow much better than a rigid, highly elastic cement binder, and it has been my experience—I have sections of Portland-cement concrete road laid with a variety of rocks—that wherever a blow strikes a piece of quartzite, for instance, it generally shivers it. If it is shivered, a cement binder readily releases the broken fragments; whereas a bituminous binder rather tends to mash and retain it. I think we will find that the same rule applies to all binders, that if they hold the rock in place, the hardest and toughest rock is going to give the longest resistance to wear.

MR. E. S. LARNED.—I should like to ascertain Mr. Page's views in regard to the form and size of particles of the coarse aggregate used in concrete road construction, as to how these might affect the value of pavement. For instance, consider stones that sliver or splinter, stones that break into cubical form, or the round stones of gravel formation, irrespective of their texture or coefficient of hardness or toughness. **Mr. Larned.**

MR. PAGE.—I do not think that is a very serious phase of the subject, although if you put crushed quartzite in a road, it does not make any difference what the binder is, it is much more liable to fracture on account of its angularity than if you were to put quartz pebbles in. If you put rounded quartz gravel in a road and a blow is struck on a single pebble, the impact is distributed much more generally to the binder and is much less likely to fracture the pebble than if a blow is delivered on an angular fragment. **Mr. Page.**

MR. LARNED.—That answers my question in a measure, but I had in view not so much the question of injury to a given particle in the binder, as that of the integrity of the concrete as a whole. How will the bond and strength throughout the thickness of the pavement be affected by the size, form and surface character of the coarse aggregate? **Mr. Larned.**

MR. PAGE.—Are you referring now to a Portland-cement binder? **Mr. Page.**

MR. LARNED.—Yes; a Portland-cement binder. **Mr. Larned.**

MR. PAGE.—I may say that we have found in the sections of concrete pavement we have laid, that the broken stone aggregates show very much less cracking due to contraction with exactly the same mixture and about the same density, than do the gravel aggregate concretes. But the pavements that we have laid have not yet been down long enough to judge what the ultimate result is going to be. I think, however, that we shall find that the trap rocks offer the highest resistance to wear. **Mr. Page.**

LARGE-CAPACITY TESTING MACHINES IN UNITED STATES AND ENGLAND.

By E. L. Lasier.

Three of the large testing machines of this country have previously been described in detail in the Proceedings of this Society. This paper is not intended to be an extensive description of any such machines. It is intended rather to be a compilation of large testing machines having not only large capacity for the load capable of being exerted, but also having the capability of being able to accommodate large-size specimens, and not merely test bars of limited dimensions.

As machines of 500,000-lb. capacity or under are more or less common, the compilation herein given involves only testing machines of 600,000-lb. capacity or greater.

A list of machines of 600,000-lb. capacity or larger is given in Table I, together with a brief description of each machine, as far as is possible so to do in such a tabular form. From a perusal of the list in Table I, the following brief summary may be drawn:

23 machines of 600,000 lb. or larger:
20 machines in the United States and 3 in England.
10 machines of 1,000,000 lb. or more, all in the United States:
3 hydraulic-power, mercury-gage weighing system.
3 hydraulic-power, pressure-gage weighing system.
2 hydraulic-power, Emery scale weighing system.
5 hydraulic-power, balance-beam weighing system.
10 screw-power, balance-beam weighing system.
18 machines accommodating both tension and compression specimens:
4 machines for compression only.
1 machine for tension only.

Some of the principal and largest testing machines are shown in Figs. 1 to 8 inclusive.

TABLE I.—LARGE-CAPACITY TESTING MACHINES IN THE UNITED STATES AND ENGLAND.

Machine.	Type.	Capacity, lb.		Power.	Weighing Device.	Maximum Length of Specimen, ft.		Date of Completion.
		Tension.	Compression.			Tension.	Compression.	
Bureau of Standards, Pittsburgh, Pa.	Vertical	None	10 000 000	Hydraulic	Balance Beam	None	25	1912
American Bridge Co., Ambridge, Pa.	Horizontal	4 000 000	None	Hydraulic	Mercury Gage	42	None	1905
Phœnix Iron Co., Phœnixville, Pa.	Horizontal	2 800 000	2 800 000	Hydraulic	Mercury Gage	50	55	1886
Bureau of Standards, Washington, D. C.	Horizontal	1 150 000	2 300 000	Hydraulic	Emery Scale	33	33	1913
United States Steel Co., McKeesport, Pa.	Horizontal	1 200 000	800 000	Hydraulic	Mercury Gage	40	32	....
Rensselaer Polytechnic Institute, Troy, N. Y.	Vertical	None	1 200 000	Hydraulic	Balance Beam	None	3	1909
Bureau of Standards, Washington, D. C.	Vertical	None	1 000 000	Hydraulic	Pressure Gage	None	9	1909
Department of Public Works, Philadelphia, Pa.	Vertical	None	1 000 000	Hydraulic	Pressure Gage	None	3	....
Pennsylvania Railroad Co., Altoona, Pa.	Vertical	1 000 000	1 000 000	Screw	Balance Beam	4	4	Unfinished
American Steel Foundries, Alliance, Ohio	Vertical	1 000 000	1 000 000	Screw	Balance Beam	3	3	Unfinished
Watertown Arsenal, Watertown, Mass.	Horizontal	800 000	800 000	Hydraulic	Emery Scale	20	26	1879
Lehigh University, South Bethlehem, Pa.	Vertical	800 000	800 000	Screw	Balance Beam	24	24	1910
Joshua Buckton & Co., England	Horizontal	784 000	784 000	Hydraulic	Balance Beam	20	5	....
Joshua Buckton & Co., England.	Horizontal	672 000	672 000	Hydraulic	Balance Beam	80	80	1909
Birmingham University, England	Horizontal	672 000	672 000	Hydraulic	Balance Beam	33	30	1909
Bureau of Standards, Pittsburgh, Pa.	Vertical	600 000	600 000	Screw	Balance Beam	24	30	....
Rensselaer Polytechnic Institute, Troy, N. Y.	Vertical	600 000	600 000	Screw	Balance Beam	22	24	....
University of Illinois, Urbana, Ill.	Vertical	600 000	600 000	Screw	Balance Beam	22	25	1905
University of Pennsylvania, Philadelphia, Pa.	Vertical	600 000	600 000	Screw	Balance Beam	22	24	1908
University of Wisconsin, Madison, Wis.	Vertical	470 000	600 000	Hydraulic	Pressure Gage	10	12	1907
Baltimore & Ohio Railroad Co.	Vertical	600 000	600 000	Screw	Balance Beam	22	24	....
American Steel & Wire Co., Pittsburgh, Pa.	Vertical	600 000	600 000	Screw	Balance Beam	22	2	....
Pressed Steel Car Co., Pittsburgh, Pa.	Vertical	600 000	600 000	Screw	Balance Beam	22	24	....

Fig. 1 shows the largest testing machine in the world,—the 10,000,000-lb. machine of the Bureau of Standards at its laboratories in Pittsburgh, Pa. A brick pier 4 by 4 ft. square is shown in position and under test. This machine has attracted wide attention and has been described in several previous

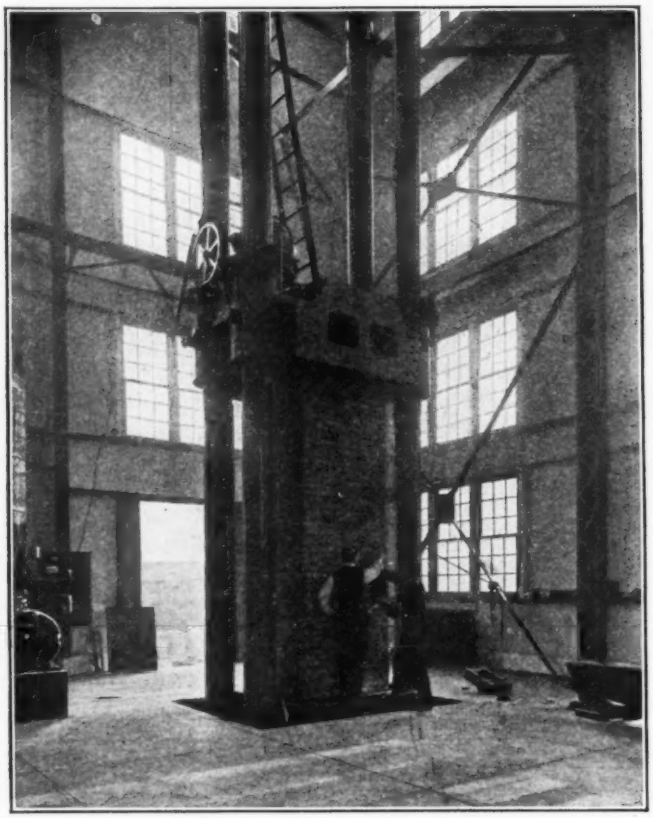


FIG. 1.—10,000,000-lb. Testing Machine, Bureau of Standards.

articles. It consists of a base casting carrying a large hydraulic cylinder and moving head, adjusted by means of nuts acting on the four main screws. Loads are applied by means of a hydraulic pump forcing liquid into the main cylinder in the base of the testing machine and weighing the same by means of a

system of levers which are actuated by the piston of the smaller hydraulic cylinder in communication with the larger one in the base of the machine.

Fig. 2 shows the Phœnixville press, next to the oldest of the large testing machines, the famous one at the Watertown Arsenal ranking as the oldest. It is likewise a hydraulic machine, the pressure being measured by a mercury gage, instead of by a balance beam, pressure gage or Emery scale. The photograph shows a built-up column placed between the compression blocks.

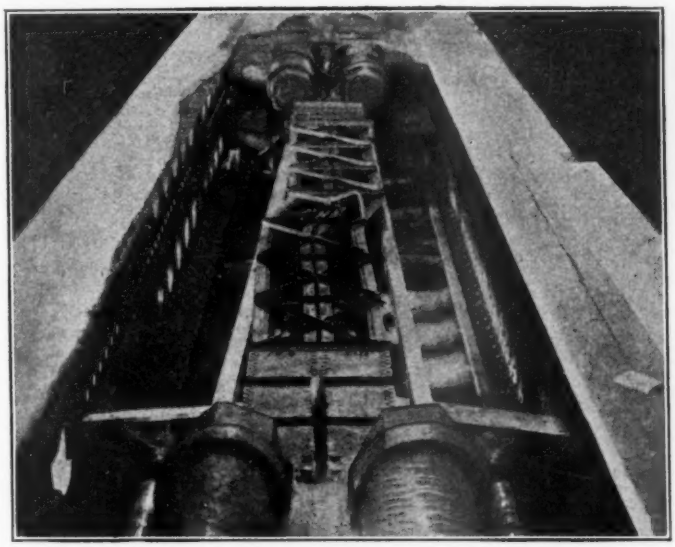


FIG. 2.—Phœnixville Press.

Fig. 3 shows the large Emery testing machine at the Bureau of Standards in Washington. This machine should unquestionably be ranked as the largest precision testing machine in the world, having a sensibility of one part in 10,000 from zero to full load, and at no point is in error more than two pounds.

Fig. 4 shows the 1,000,000-lb. machines for compression only, at the Bureau of Standards, Washington, D. C., the Department of Public Works, Philadelphia, Pa., and the Rensselaer

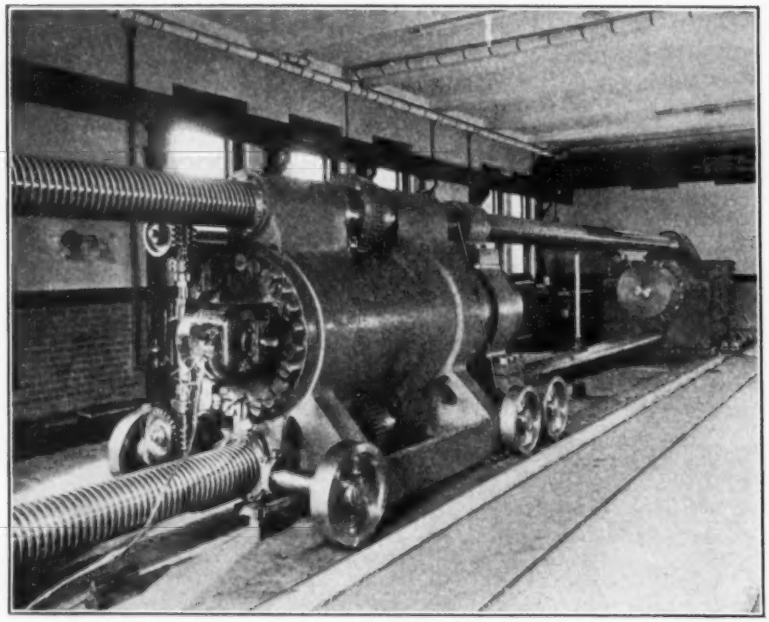


FIG. 3.—Emery Testing Machine, Bureau of Standards.

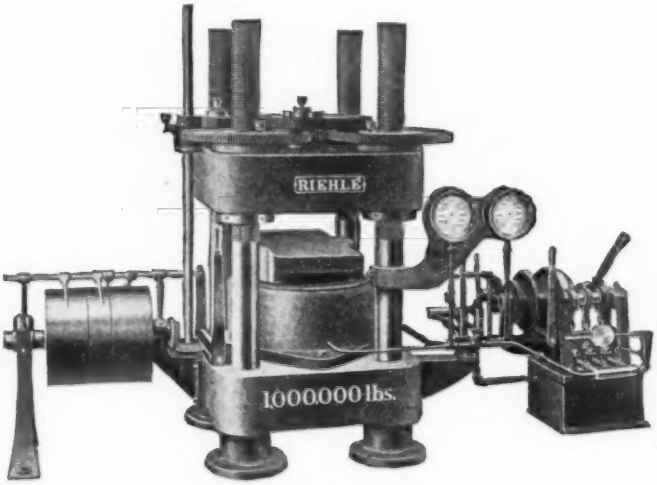


FIG. 4.—Compression Machines, 1,000,000-lb. Capacity.

Polytechnic Institute, Troy, N. Y. The loads in this machine are weighed by means of a system of pressure gages of increasing capacities, so that each successively higher range gage may be thrown into play when the preceding lower range has been exceeded.

The 1,000,000-lb. testing machines at present being built for the Pennsylvania Railroad Co. at Altoona, Pa., and the American Steel Foundries at Alliance, Ohio, will be lever machines

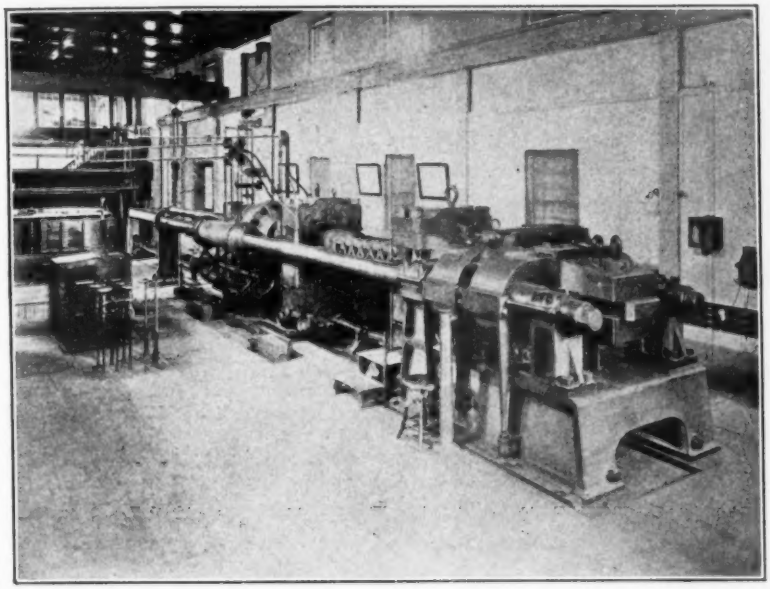


FIG. 5.—Emery Testing Machine, Watertown Arsenal.

and will be the largest screw-power testing machines in the world.

Fig. 5 shows the Emery testing machine at the Watertown Arsenal, which was the standard large testing machine for so long and has done such excellent work in tests upon full-size members.

Fig. 6 shows the 800,000-lb. machine in the Fritz Engineering Laboratory of Lehigh University. The photograph shows a reinforced concrete column 15 in. in diameter and 20 ft. long in place ready for testing.

Figs. 7 and 8 show the apparently only large testing machines in England. Fig. 7 is a machine of the Joshua Buckton Co. Fig. 8 is the testing machine used in the Birmingham University. It is interesting to note that in both of these

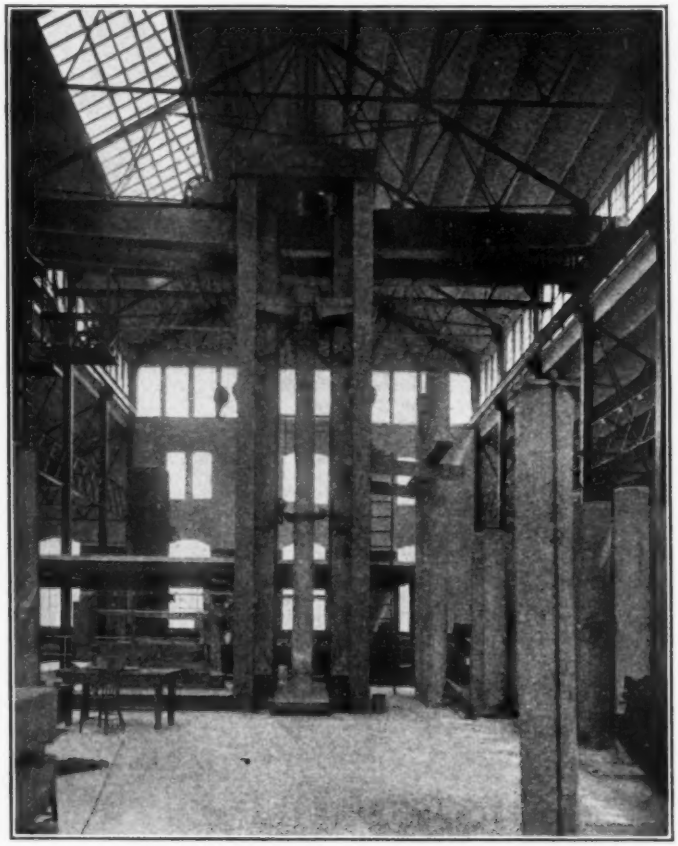


FIG. 6.—Lehigh University, 800,000-lb. Testing Machine.

machines, facilities are afforded for making tests in deflection upon beams up to 20 ft. between supports for the Buckton machine, and 30 ft. for the Birmingham machine. The Buckton machine is also able to test specimens in torsion up to a moment of 300,000 in-lb., and can test in shear up to

its full capacity. The machine has a sensibility of within 1/10,000 of its load up to 100 tons.

The above compilation and brief description of the large

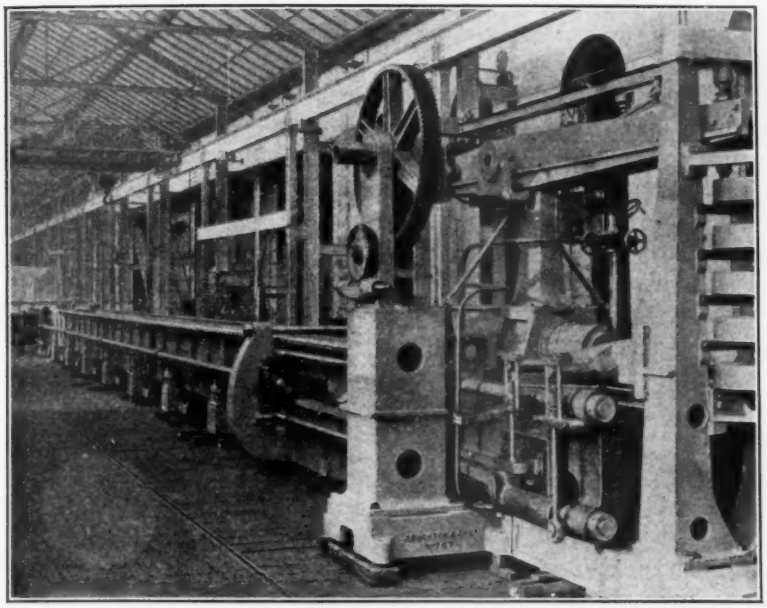


FIG. 7.—Testing Machine, Joshua Buckton Co., England.

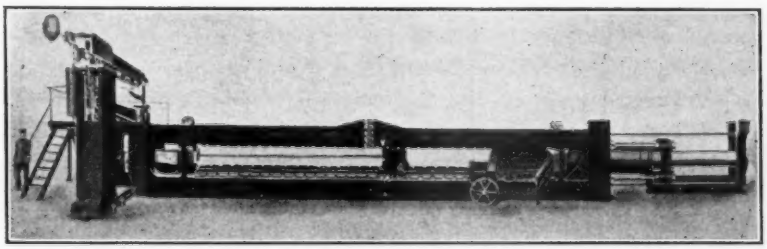


FIG. 8.—Testing Machine, Birmingham University, England.

testing machines in this country and in England has been given because of the increasing interest in, and importance of, tests upon structural members as they are actually used in service.

SPHERICAL BEARINGS.

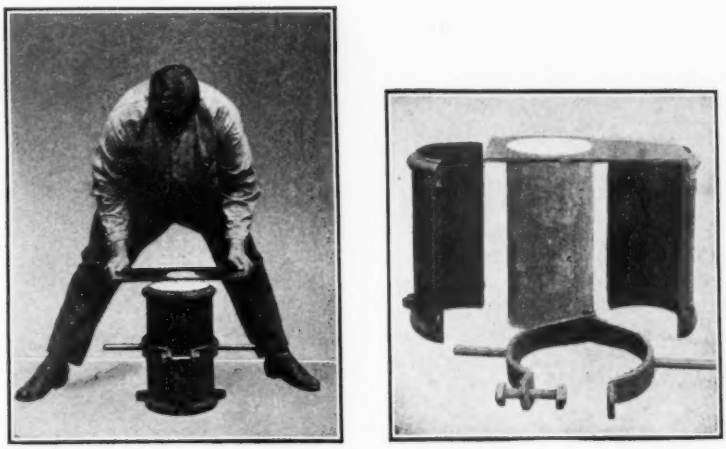
By Mont Schuyler.

The use of spherical bearings in the compression test is almost universal. This is particularly true in testing concrete and other friable materials. Frequently in making tests on long columns the bearing is dispensed with, since structural members are generally considered as having fixed ends. The standard methods for testing adopted by the American Society for Testing Materials demand the use of a spherical bearing but make no mention at all of the details of the design. Professor Kirsch, of Vienna, at the Sixth Congress of the International Association for Testing Materials, called attention to several of the questionable points arising in the use of spherical bearings and requested the appointment of a committee to more thoroughly examine these points.

With the above in mind I felt that a partial discussion of at least some features of spherical bearings might be apropos at this time. The matter given below is mainly in connection with the experience of the Municipal Testing Laboratory of St. Louis in the use of these bearings.

There are two different viewpoints from which the question may be considered. First, as a method of adjustment to correct any lack of parallelism which may exist between the two ends of a compression specimen; and second, as a means of allowing adjustment during the progress of testing so that in general the distribution of pressure may be uniform over the ends. From my personal observation I should judge that the first of these is generally considered to the exclusion of the second, although this is neither justified by *a priori* consideration nor experimental data. Furthermore, it should be pointed out that even if the second condition is expected, that is, movement during the test, correct conditions are not obtained in most cases. That is to say, even though the bearing moves freely there is no assurance that the distribution of pressures is uniform, as will be pointed out later.

Parallelism is readily obtained by correctly grinding the ends, or preferably, in the case of cement products, by plaster-of-Paris caps; so that it probably is an injustice to subject a specimen to compression test upon a bearing which does not move freely throughout the period of stressing. The variables introduced through the plaster-of-Paris cap are indeterminate, it is true, but probably if correctly applied do not affect the strength to any marked degree, as has been shown frequently by comparative tests. As a general rule, however, plaster-of-Paris caps are not applied in a manner which will result in true



(*a*) (*b*)

FIG. 1.—Method of Capping with Plaster of Paris.

parallelism between the ends. Capping in the machine itself will accomplish this, but at considerable cost in time and patience. A very simple method has been developed in use with some success in the Municipal Testing Laboratory which it is thought fit to mention here in passing.

This method, illustrated in Fig. 1, consists essentially in clamping the specimen in the mold in which it was cast, allowing a recess at one end into which the plaster-of-Paris paste is poured and leveled off by means of plate glass well oiled and pressed down until the excess plaster paste has been forced out

between the ends of the mold and the plate glass. By this means plaster caps of any desired thickness may be obtained, with the assurance, if the mold has been correctly made and trued up in the lathe, that the surface is perpendicular to the axis of the specimen. The operation may be repeated at the other end and a capped specimen secured, which is theoretically correct if the propriety of using plaster of Paris is granted.

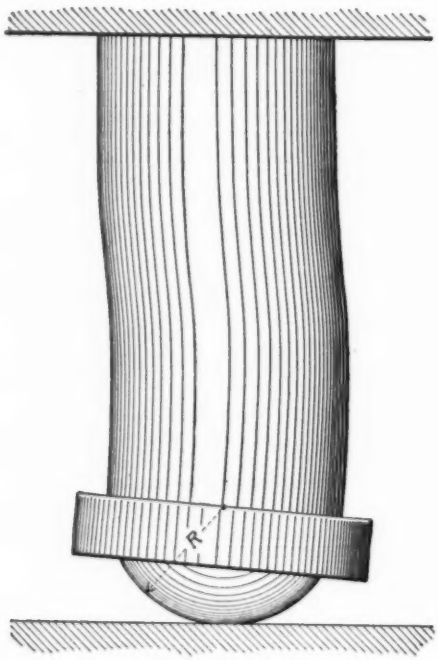


FIG. 2.—Hemispherical Bearing.

There are four general classes of spherical bearings. First, a hemisphere on the equatorial plane of which the specimen rests. The sphere itself touches the bed of the machine and is free to move in response to any lack of uniformity in the distribution of pressures, with very slight resistance beyond that introduced by the imperfect elasticity of the metal of the bearing and of the machine table. This design is faulty, due

to the fact that any movement tends to bend the specimen, as indicated in Fig. 2.

The second design, that of the ball and socket, is faulty when the radius of the sphere is of such a length that its center lies in the body of the specimen. Due to the smallness of the turning moments introduced by lack of uniformity of modulus in the specimen, this bearing very seldom moves during the

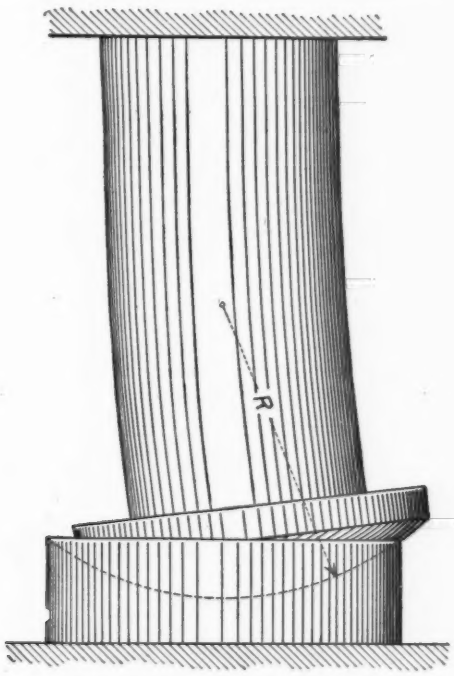


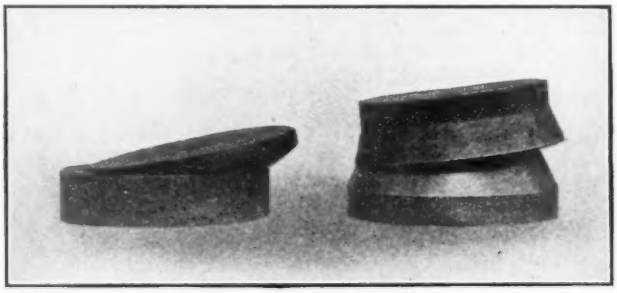
FIG. 3.—Long-Radius Bearing.

progress of the test and, when this movement occurs, subjects the specimen to a bending moment as indicated in Fig. 3. A usual form of this bearing is shown in Fig. 4 (a_1 and a_2), which is a photograph of the first design used in the Municipal Testing Laboratory. It was provided with an axial hole through which the bar of a "pull-out" test for bond value could project.

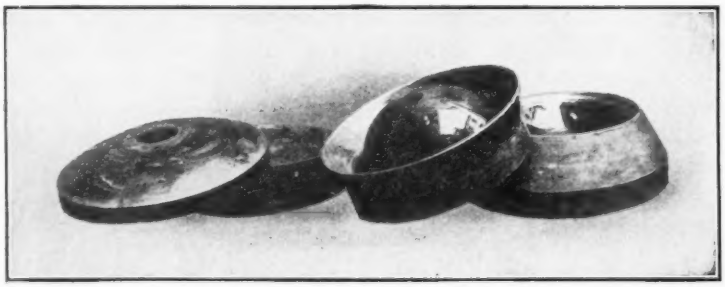
The third design is that adopted as standard by this Society for the compression test of cement, shown in Fig. 5. It consists

of a ball of small radius set in two blocks, one resting against the head of the machine and the other being part of the bearing plate through which pressure is transmitted to the specimen. This suffers from faults of approximately the same order as those possessed by the bearing illustrated in Fig. 2.

To avoid the bending which will be introduced by move-



(a_1) (b_1)



(a_2) (b_2)

FIG. 4.—a_1 and a_2, Long-Radius Ball-and-Socket Bearing.
b_1 and b_2, Correct-Radius Ball-and-Socket Bearing.

ments of the bearing, it may be readily seen from an examination of Fig. 6 that the center of the sphere must lie in the end surface of the specimen. The turning tendency is here not so great as when a ball of small radius is used, but it is larger than when spherical bearing of long radius is employed. To offset this apparent disadvantage in comparing it with the short radius, it must be granted that no bending strains are intro-

duced into the specimen through its use, originally vertical fibers remaining vertical, and plane transverse sections of the specimen remaining in general planes.

It should be mentioned here that theoretically two spherical bearings should be used. Allowing the total difference in deformation existing between two sides of a specimen to be taken up at one end, undoubtedly generates shear between

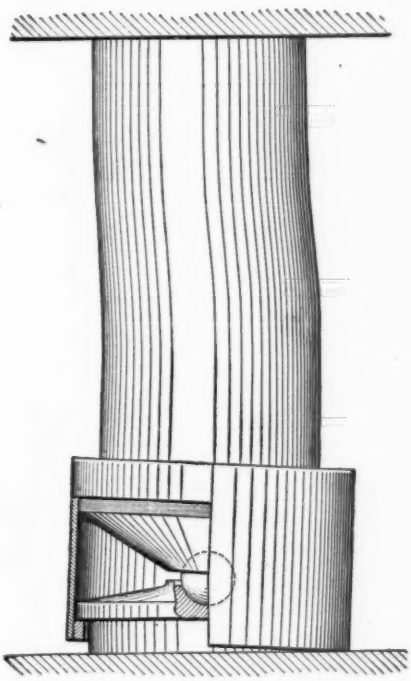


FIG. 5.—Short-Radius Bearing.

axial elements which would not exist to so great an extent were bearings used to transmit the load from the machine at both points of application.

The question of lubrication is one that is affected by the same factors considered above; that is, whether any movement is desired during the test determines whether a lubricant should be employed. If it is desired that movement be allowed

during progress of the test, the question of a lubricant assumes a formidable aspect. A light oil will not do, and I have found no straight heavy oil which seemed satisfactory for the purpose. The use of deflocculated graphite in dynamo oil has made possible extremely efficient lubrication. A lubricant of this nature does not seem to be forced out by even the highest pressures and after a test a well-ground bearing moves as freely

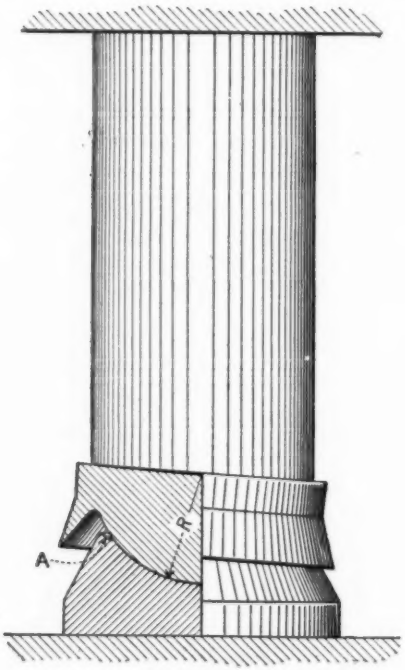


FIG. 6.—Correct-Radius Bearing.

as it did before the test. By designing the bearing with a small oil ring as shown at *A* in Fig. 6, the excess oil is caught and the bearing thus has a method of partially relubricating itself from time to time; or the upper hemisphere may be raised slightly, allowing the oil to re-establish lubrication.

If the bearing is loaded much beyond 10,000 lb. per sq. in. of projected area it is extremely probable that movement, if it occurs at all, proceeds by jumps. By mounting the spherical

bearing as shown in Fig. 7, the oil in the hydraulic cylinder may be allowed to flow under pressure through the valve *A* into the spherical bearing and, furthermore, by partially relieving the load in the bearing surfaces, make continuous lubrication more probable.

Several stress-strain diagrams are shown (Figs. 8 to 10

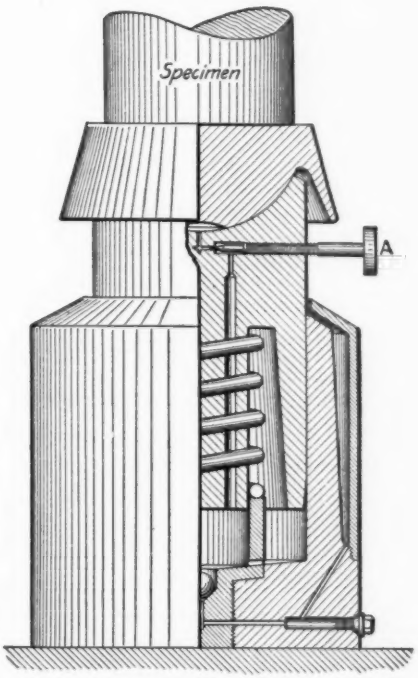


FIG. 7.—Self-Lubricating Bearing.

inclusive), which indicate that with the correct radius of bearing and proper lubrication movement actually does take place, and frequently in unexpected directions. By the employment of a three-point rigging and Berry strain gages, as illustrated in Figs. 11 and 12, the three dotted curves shown were obtained on various specimens, which curves show a decided departure from what is usually expected. An average of three curves, however, results in an extremely smooth and uniform

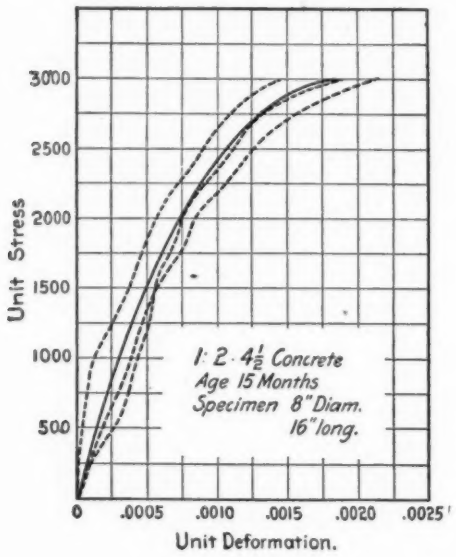

3000
2500
2000
1500
1000
500
Unit Stress
1:2:4½ Concrete
Age 15 Months
Specimen 8" Diam.
16" long.
0
.0005
.0010
.0015
.0020
.0025
Unit Deformation.

FIG. 8.

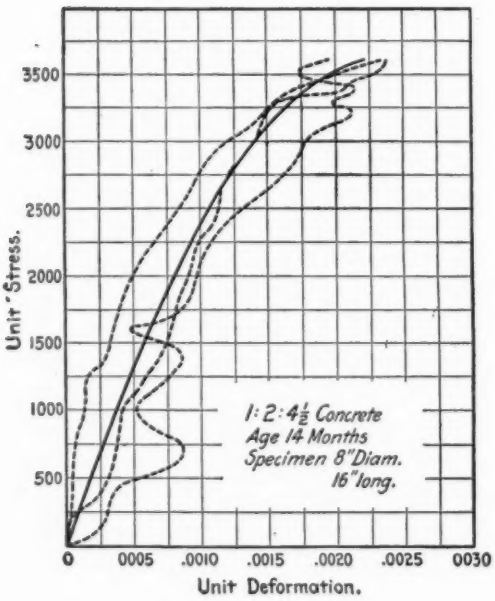

3500
3000
2500
2000
1500
1000
500
Unit Stress.
1:2:4½ Concrete
Age 14 Months
Specimen 8" Diam.
16" long.
0
0005
.0010
.0015
.0020
.0025
0030
Unit Deformation.

FIG. 9.

stress-strain diagram; and this would seem to establish the fact that the modulus, even in a small specimen 8 in. in diameter and 16 in. long, varies considerably from side to side, although the average obeys the generally accepted laws.

Even with correct design of the usual spherical bearing one thing is not accomplished, and that is a distribution of pressures over the end surfaces so that each elemental area receives the same intensity of pressure as each other elemental area. Certainly, if the validity of the stress-strain diagrams

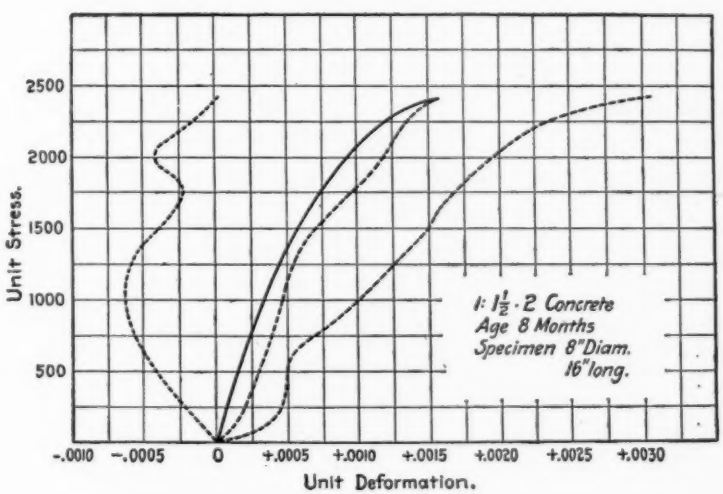


FIG. 10.

shown is accepted, it must be seen that the pressures must vary considerably from point to point; and if a hard plate is used through which to transmit the pressure, it is very probable that in certain extreme cases an area of but 25 per cent of the cross-section of the specimen must carry 75 per cent of the load. To avoid this we have designed a special bearing which accomplishes these three things: first, it provides a perfect substitute for the spherical bearing; second, it allows extension of the specimen transversely; and third, it distributes the pressures uniformly over the end.

This bearing is illustrated in Fig. 13; the drawing itself

is explanatory and requires no comment. By means of this bearing we have obtained some rather unusual results. Fig. 14 shows a photograph of a 3 by $4\frac{1}{2}$-in. cylinder broken on this special bearing. It may be seen that this specimen has split into three parts, fracture taking place along planes passing through the approximate axis of the specimen.

Only one of these bearings has been constructed and we have not had entire success with the diaphragms which have been used so far. At the present time we are experimenting with a diaphragm composed of a layer of sheet rubber protected

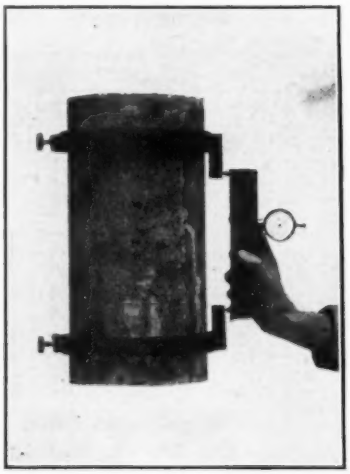


FIG. 11.

at its top with a thin sheet of rawhide leather. This combination makes the rubber sheet last longer by preventing its bursting when the specimen fails, and furthermore avoids the shearing stresses generated in the small clearance between the specimen and the top retaining lip of the bearing. The compressive strength as recorded when this bearing is used does not depart radically from the strength developed in parallel specimens tested in the usual manner.

We have attempted to analyze the distribution of horizontal stress generated in a specimen crushed between two bearings of this nature by the methods of the theory of least

work, but have not arrived at any satisfactory conclusion. At this time it seems probable that there is no bursting tendency and hence no shear generated by axial loads uniformly distributed over the ends.

It is therefore difficult to explain why the radial breaks occur when this bearing is used, but we have come to the con-

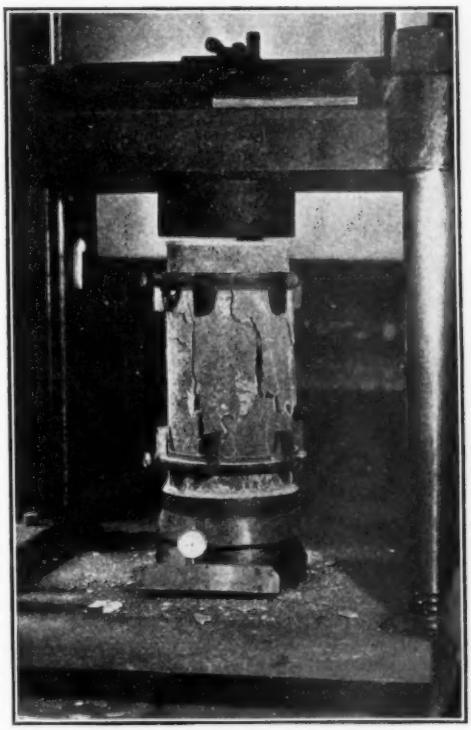


FIG. 12.

clusion that it is probably due to the fact that, as only one bearing has been employed so far, the splitting action is caused by the incipient cone which is formed on the top of the specimen due to the constricting effect of a rigid bearing plate. This cone is similar in all respects to the cone found when a compression specimen is tested in the usual manner.

We do not feel at the present moment that, in spite of the avoidance of capping, it will prove possible to adapt this particular bearing to routine testing. The temporary nature of

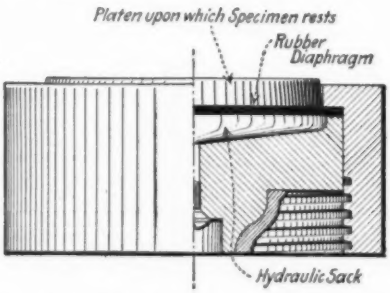


FIG. 13.—Modified Diaphragm Bearing.

the diaphragm would make it a troublesome and expensive bearing to keep up, and, though we have not dropped work



FIG. 14.

on this point, we feel that perhaps the apparatus has only a theoretically interesting aspect. It is possible, however, to use this design as a basis and to construct a rigid end plate bearing

which will replace the usual spherical bearing and avoid the many uncertainties inherent in this design. Fig. 15 shows the general scheme, the alteration consisting in the insertion on the rubber diaphragm of an accurately fitted disk which takes on its top surface the specimen and transmits the pressure through the water sack and the interposed rubber diaphragm to the machine. In this bearing the effects of long radii are practically eleminated and movement without friction is obtained. It is believed that this bearing will be extremely rigid, simple to keep up, and particularly desirable in delicate work.

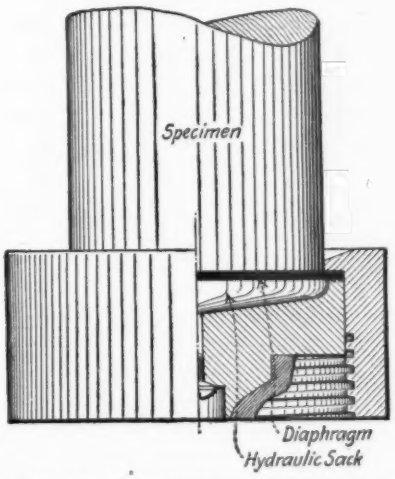


FIG. 15.—Elastic Diaphragm Bearing.

SUMMARY.

It is the usual practice to use the spherical bearing when making tests in compression. The bearing may be used either to correct for lack of parallelism in the ends of the specimen or to allow an adjustment and equalization of pressures on planes perpendicular to the axis of loading during the progress of the test. In general it may be said that the first condition only is met.

Even when movement during the test is expected and provided for, the design of the usual spherical bearing is incorrect in that any movement of the bearing tends to induce a bending

moment in the specimen. This tendency is avoided by placing the specimen on the equatorial plane of the sphere of a ball-and-socket bearing.

Even when this is done, however, there is no assurance that pressures are uniformly distributed over the ends. By the use of an elastic diaphragm which incloses a hydraulic sack and takes the pressure from the specimen on its top face, correct conditions are obtained. In addition, the use of a plaster-of-Paris cap is avoided and the effect of constricting the ends of the specimen, due to friction against the hard bearing plate, is eliminated.

By the addition of a rigid disk to the above apparatus a theoretically perfect substitute for the usual spherical bearing is secured. A more serviceable bearing is perhaps obtained in this way, but capping is necessary and end friction still exists.

USE OF THE STRAIN GAGE IN THE TESTING OF MATERIALS.

By W. A. Slater and H. F. Moore.

At the 1910 meeting of the American Society for Testing Materials an extensometer of the form here termed "strain gage" was exhibited. The acquaintance of the writers with this form of extensometer dates from that time. Since then they have been identified with the application and adaptation of it to measurements of deformation in a large number of laboratory and field tests and with the development of methods of determining and applying the necessary corrections to the observations.

Before discussing the use of any one kind of extensometer, it may be well to classify the uses to which extensometers usually are put and to mention the characteristics of various types of extensometers.

The use of an extensometer as considered here is always the measurement of the change in length in a certain predetermined portion of the material being tested. The purpose of its use may be to determine the properties of the material, or it may be to determine the amount of deformation in a certain structure under working conditions. An example of the former purpose is the determination of the modulus of elasticity, the limit of proportionality between stress and deformation, or the coefficient of expansion, of some particular kind of steel. An example of the latter use is the determination of the amount of deformation in an eyebar due to the load for which it was designed, or the measurement of the deformation in a given length of brick pavement, due to a change in temperature such as occurs in the place where the pavement is used. The two problems may be characterized as the determination of properties of materials and the determination of the actual distribution of deformations. In laboratory tests either problem may be met. In field tests, as a rule, only the latter problem is undertaken.

The term "strain gage" as used here may be considered to mean any kind of an extensometer which during the course of a single test may be used to measure changes of length in various portions of the structure or specimen being tested. In distinction from this, the "fixed extensometer" may be taken to be an extensometer which is attached to the specimen or set in place before the test is begun and which must remain in place throughout the test, not being available for measurement at any other portion of the test specimen. Before discussing the strain gage, some of the characteristics of the fixed extensometer will be outlined.

The field of the fixed extensometer is in general the determination of average properties of materials by means of laboratory tests. For this purpose it has considerable advantage over the strain gage in that it may be so arranged as to give mechanically the average of a number of readings at various portions of the test piece. For instance, in determining the modulus of elasticity of a bar of steel in compression the extensometer may be so attached as to give as a single reading the average of the deformations on opposite sides of the test piece. It has been shown that from the deformations thus measured the modulus of elasticity of the material may be determined with considerable accuracy, even though there may be eccentricity of loading and consequently a difference between deformations on the two sides. For comparison of moduli of elasticity of various materials then it would be possible in some cases to attach extensometers in the manner described above, and to take readings of average deformations very rapidly, while with the movable extensometer it would be necessary to obtain a larger number of readings and use the average. For instance, in the testing of a column 10 ft. long the fixed extensometer could be used to give as a single reading the average of the deformations on both sides of the column over a gage length of 100 in. To obtain the same information by the use of the movable extensometer, it would be necessary to take, say 20 separate observations and use their average.

The limitations of the fixed extensometer usually occur in the case where it is desired to find out not the properties of the material in the test specimen, but the actual distribution of the

deformations. These limitations are due to various causes, several of which are here discussed.

1. In case measurements are required in a large number of places, the cost of fixed extensometers would be prohibitive. In the Laboratory of Applied Mechanics of the University of Illinois as many as three tests have been in progress at a time, in any one of which measurements were taken at from 50 to 100 positions. The cost of fixed extensometers to equip such tests as these would be in the neighborhood of $3000 as a moderate estimate. Moreover, the difficulty, if not the impossibility, of attaching so many extensometers in such a way as not to interfere with each other would prohibit their use. The length of time required to prepare for such a test as this would be enormous.

2. In tests of long duration, such as tests of large areas of a floor which require a considerable length of time for loading, it would be very difficult to prevent disturbance of instruments by persons not appreciating the requirements of great care, and it would be difficult to make temperature corrections. Slight drafts of air also frequently affect seriously the accuracy of readings obtained on fixed extensometers, depending, of course, on the form of extensometer used.

3. Frequently it is difficult or impossible to attach an instrument to the specimen being tested. For instance, in the case of a reinforced concrete slab it is well-nigh impossible to attach an extensometer directly to the steel and only slightly less difficult to attach it to the concrete. When attached to the concrete, the formation of cracks frequently gives very misleading results.

4. Most forms of attached extensometers measure change of length not in the extreme fiber of the member, but along a line at some distance from the surface, and in order to determine the extreme fiber deformation it is necessary to take measurements on opposite sides of the member. From these two measurements, the neutral axis may be located (assuming "conservation of plane sections"), and the deformation at the surface calculated. For this method of measurement the time required in preparation for an extensive test would be very great, and the reducing of the data would be complicated: the correctness

of measurement at any point would be dependent upon the correctness of the measurement on the opposite side, upon the presence of cracks in the material and upon the correctness of the assumption of "conservation of plane sections." Furthermore, it is sometimes impossible to place fixed extensometers on both sides at a place where it is very necessary to determine stresses. An illustration of this is shown in Fig. 1, which represents a section at an interior support of a reinforced concrete flat slab floor. Critical steel stresses may be expected to occur at sections *A-A* and *B-B*, and it is important that the deformations across these sections be determined. Manifestly, it is impracticable to measure deformations on the bottom across these sections, as would be necessary with fixed extensometers,

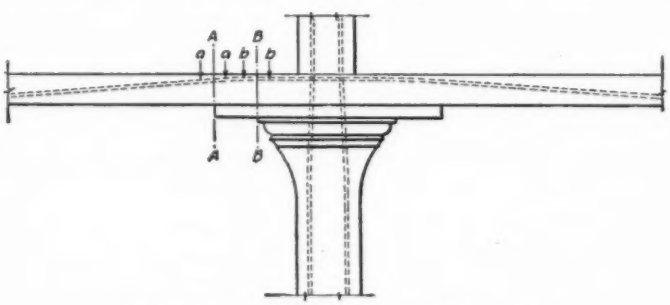


FIG. 1.—Section at Support of Flat Slab Floor.

but it is a comparatively simple matter to place gage lines at *a-a* and at *b-b* and to use a strain gage for the direct measurement of deformation in the steel.

Many of the limitations of the fixed extensometer described above are overcome in a great measure by the strain gage, the use of which is discussed in the following paragraphs.

The requirement of measurements over short gage lengths and over a larger number of them than could be obtained by using a fixed extensometer, led to the adoption of various methods of measuring large unit deformations in laboratory tests. These were originally crude methods and generally were applicable only where the test piece had passed the yield point and where the deformation on a gage length of a

few inches was consequently so large that it could be read by the unaided eye on a scale graduated to hundredths of an inch.

This is well illustrated by tests made on small eye bars at the University of Illinois. The method has been used in many laboratories. On the heads of the eye bars $\frac{1}{2}$-in. squares were scribed and the deformation of these squares measured with dividers during and after the test. This crude method did not, of course, yield any reliable measurements of elastic deformation, but did show when the yield point of the material was locally exceeded and showed in a general way the distribution of stress. The results obtained in this way were crude, but the procedure demonstrated one method of overcoming the limitations of the fixed extensometer.

Several forms of sensitive dividers have been used for measuring change of length between punch marks or other gage points on test specimens. Two such instruments are (1) Capp's multiplying dividers, described in the Proceedings of this Society[1] for 1907, and (2) a mercury column strain gage described on page 26 of "Tests of Metals" (Watertown Arsenal) for 1906. These instruments were used with success in locating the yield point in tension tests of metals.

Two types of strain gage of sufficient precision for the measurement of elastic deformations are in use in this country at the present time, one devised by Mr. James E. Howard of the United States Bureau of Standards and the other devised by Prof. H. C. Berry of the University of Pennsylvania.

The Howard strain gage, which was used at the Watertown Arsenal as long ago as 1888 and which has become better known to the public within the past few years, operates on the principle used in the deformation measurements on eye bars previously cited. In using this instrument carefully drilled and countersunk holes are used instead of prick-punch marks. It is, in brief, a pair of trammels mounted on a telescoping frame, to which is attached a screw micrometer for the purpose of determining accurately the amount of movement of the points. Fig. 2 shows this instrument. For a fuller description of it and of work done by it, refer to "Tests of Structures," by James E.

[1] Vol. VII, p. 624.

Howard, in the Proceedings of the International Association for Testing Materials for 1912.

The Berry type of strain gage consists of a frame to which are attached a micrometer and two pointed legs; one leg is fixed in position and the other pivoted in such way that it will adjust itself to slight changes in distance between gage holes. Attached to, or continuous with, the pivoted leg is a lever arm which multiplies any movement of the point of the leg. The amount of movement at the end of the lever arm is measured by means of the micrometer attached to the frame. A strain gage of the form exhibited by Professor Berry at the meeting of this Society in 1910 is shown in Fig. 3. One differing from it only in minor details is illustrated and discussed in an article by Professor Berry in *The Engineering Record* for June 11, 1910. In both of these instruments the movement of the end of the multiplying



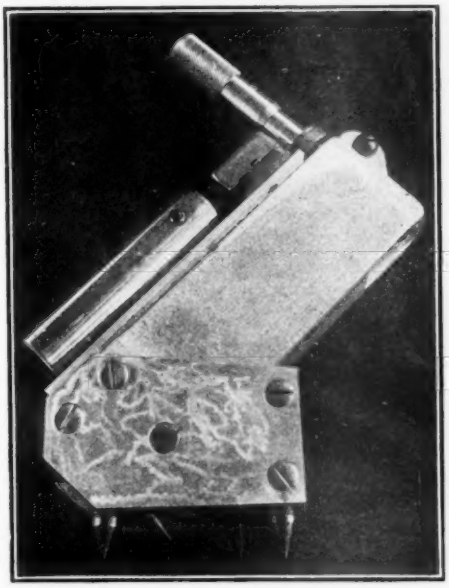
FIG. 2.—Howard Strain Gage.

lever was measured by means of a screw micrometer operated manually, the instant of contact being determined electrically. In an instrument of the Berry type (see Fig. 4) designed at the University of Illinois and first used in the test of the Deere and Webber Building in Minneapolis, Minnesota, an Ames dial micrometer was substituted for the screw micrometer. This dial is self-indicating and its use decreased the time necessary for taking measurements and greatly facilitated the operation of the instrument, enabling the use of both hands in the seating of the points. Results obtained by the use of the instruments shown in Figs. 3 and 4 are given in the paper by A. R. Lord on "A Test of a Flat Slab Floor in a Reinforced Concrete Building,"[1] and in Bulletin No. 64 of the University of Illinois Engineering Experiment Station.

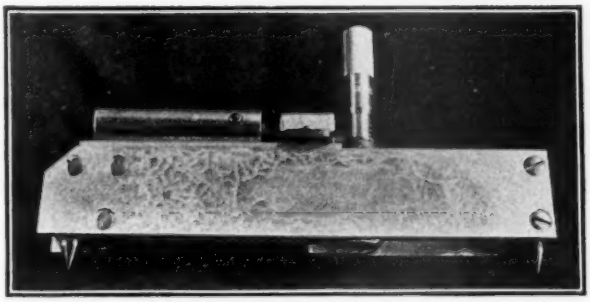
The next development of this type of strain gage made at the University of Illinois is shown in Fig. 5. In this instrument

[1] *Proceedings*, National Association of Cement Users, Vol. VII.

aluminum is used to secure lightness, and a means is provided of varying the gage length at will from 6 to 11 in. Fig. 5 shows



(*a*) 2-in. Gage Length.



(*b*) 8-in. Gage Length.

FIG. 3.—Original Forms of Berry's Strain Gage.

the principles of its operation. In Bulletin No. 64 of the University of Illinois Engineering Experiment Station, on "Tests of Reinforced Concrete Buildings under Load," by Arthur N.

Talbot and Willis A. Slater, and in a paper by Mr. Slater on "The Testing of Reinforced Concrete Buildings,"[1] a fuller description of the instrument is given and also results obtained by its use.

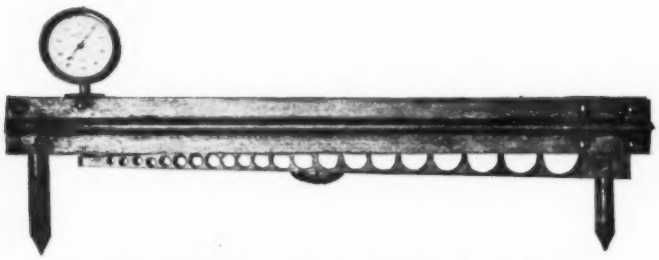


FIG. 4.—Strain Gage Designed for Deere and Webber Test.

In another modification of the strain gage the multiplying lever occupies a vertical position when measurements are being taken on a horizontal surface. This is of advantage in that it

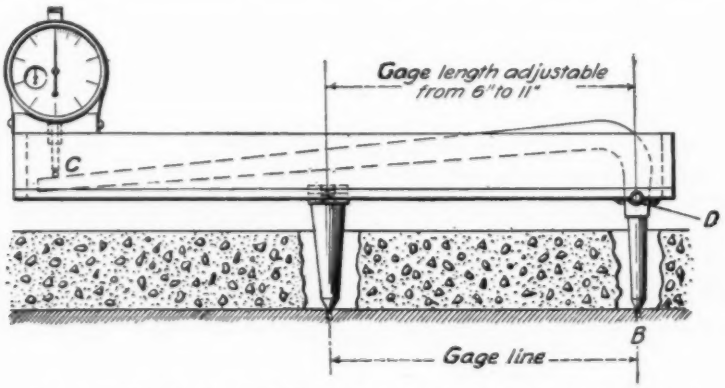


FIG. 5.—Illinois Form of Strain Gage having Aluminum Frame and Horizontal Lever.

avoids that part of the horizontal thrust on the edge of the gage hole which is due to the weight of a horizontal lever. So far as the writers know, Mr. F. J. Trelease was the first to use this detail.

[1] *Proceedings*, National Association of Cement Users, Vol. VIII.

In Fig. 6 is shown a newer form of the Berry type of extensometer designed by the writers. It has a very rigid stationary leg and a means of increasing the length of the leg without reducing the multiplication ratio, that is, the ratio of the distance between pivot of movable leg and point of bearing on plunger of Ames gage, to the distance between pivot and point of bearing on edge of gage hole. Another feature of the instrument is the use of a multiplying ratio larger than is known to have been

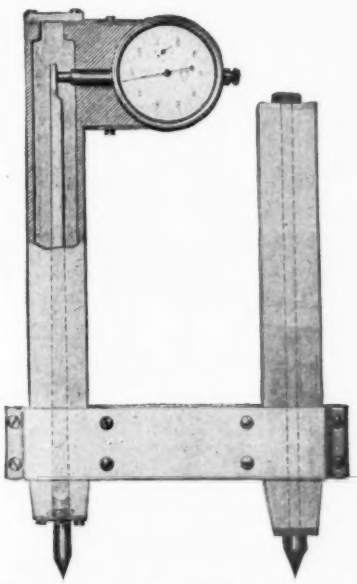


FIG. 6.—Illinois Form of Strain Gage having Aluminum Frame and Vertical Lever.

successfully used on any other strain gage. It was designed also with a view of obtaining great rigidity in the frame as regards the effect of longitudinal thrust. For this purpose the legs were made rectangular in cross-section instead of circular and to this same object was sacrificed the adjustability of gage length except for about $\frac{1}{16}$ in. which may be obtained by loosening the nut at the top of the right-hand leg in Fig. 6 and moving the leg in or out a small amount to allow for small variations in

the spacing of the gage holes. The necessity for great rigidity in the resistance of longitudinal thrust has been found in all tests where it was necessary for the observer to assume an awkward position in the measurement of deformation. This was particularly true when in a test of the Larkin Building in Chicago in August, 1912, measurements were taken of deformations in steel which had a depth of embedment in concrete of as much as 4 in. Making the multiplying lever vertical as shown in Fig. 6 instead of horizontal enables the length of leg to be increased without reducing the multiplication ratio. For a given amount of longitudinal thrust this instrument shows an error in observa-



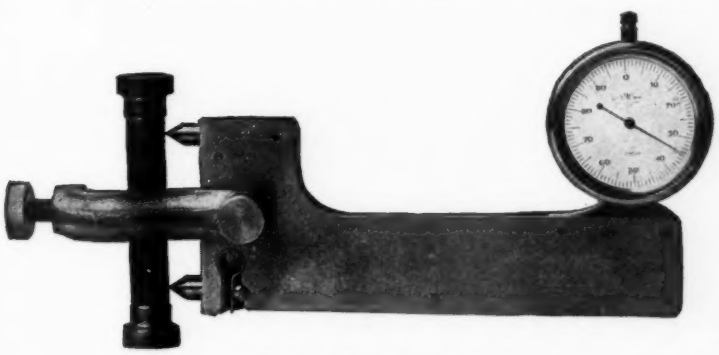
FIG. 7.—Illinois Form of Strain Gage with Horizontal Lever and 4-in. Legs.

tion about 90 per cent less than that found in a special long-legged instrument (see Fig. 7) devised for the Larkin test. The error (due to the use of long and rather flimsy legs and a small multiplication ratio) in this special instrument was much larger than is found with the forms of strain gage previously described, hence the above comparison of errors must be taken only as showing the suitability of the new instrument for cases requiring the use of an extremely long leg.

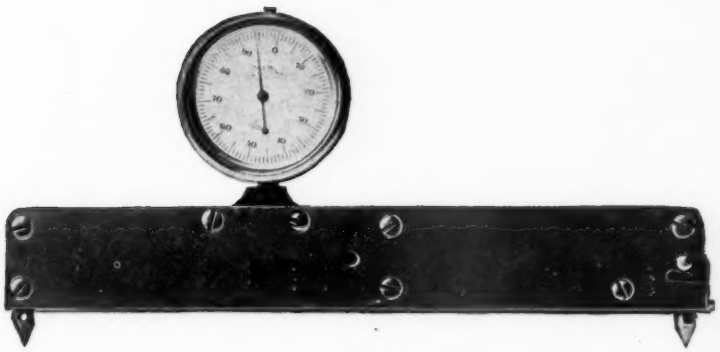
Fig. 8, furnished by Professor Berry, shows his latest form of strain gage. It is fitted with a self-indicating gage, has Invar steel sides (so that the change of instrument readings due to warming up of the instrument with handling is minimized),

and has specially designed pivot bearings. The gage length is not adjustable.

The feature common to all forms of what is here termed the "strain gage," then, is the utilization of a pair of trammel points in connection with some kind of micrometer for the measurement



(*a*) 2-in. Gage Length.



(*b*) 8-in. Gage Length.

FIG. 8.—Later Forms of Berry's Strain Gage

of the change of distance between a pair of small holes (termed gage holes) drilled in the surface of the test specimen.

In using the strain gage it is of prime importance to minimize errors due to personal equation of the observer. Under very favorable conditions of location of gage lines for measurements it has been found possible for one man to reproduce the

readings of another with a variation not greater than one ten-thousandth of an inch, but such favorable conditions rarely occur in tests. At the University of Illinois the rule has been adopted that for any gage line one observer must take a complete set of readings for the test. Another complete set of readings taken by a second observer is desirable as a check if the conditions of the test permit. The following method of taking a strain gage reading has become standard:

Place the point of the movable leg of the strain gage in one gage hole of a gage line taking hold of the instrument as near the legs as possible; avoiding jerky motion or jar, slide the point of the fixed leg into the other gage hole and read the dial, keeping the points of the legs of the instrument firmly pressed into the gage holes; repeat this process until there have been obtained a series of five consecutive readings which do not vary by more than 0.0003 in.; take the average of this series as the gage reading for an observation. When about to read the gage, it is important to keep the eye turned away from the dial until the instrument is firmly settled in position, else prejudice in favor of the first reading accompanied by involuntary muscular action will tend to produce a repetition of a previous reading.

It has not been found advisable to use the strain gage for undergraduate class work in the materials testing laboratory; this is because of the large amount of time required to acquire skill with the strain gage and the time required to take and reduce readings. The primary objects of student class work in the materials testing laboratory are to familiarize students with the properties of some of the common materials of construction and to illustrate the laws of the mechanics of materials rather than to train laboratory experts, and the simpler forms of attached extensometer have been found best suited for these objects. For undergraduate thesis work, however, the strain gage has been widely used. Nearly all students readily attain a fair degree of skill (their proficiency is tested before they are allowed to take readings in actual tests) and in some cases they have surpassed their instructors in deftness of manipulation.

The proper preparation of gage holes and gage lines is a very important factor in securing accurate measurements with the strain gage. The gage holes must be drilled deep enough

so that the points of the strain gage can not touch the bottom of the hole, and the edge of the drilled hole should be smoothed so that all burr is removed, allowing the strain-gage leg to bear against the edge formed by the smoothing action of the finishing tool. At the University of Illinois a specially designed No. 54 drill (0.055 in. diameter) has been found to give good results and a finishing tool (Fig. 9) which acts by rubbing rather than by cutting is preferred. Where electric current is available, a small electric-driven drill with a flexible shaft is used in drilling gage holes. Where electric current is not available a small hand-power drill is used. Personal supervision over the location and drilling of gage holes should be given by the person in charge

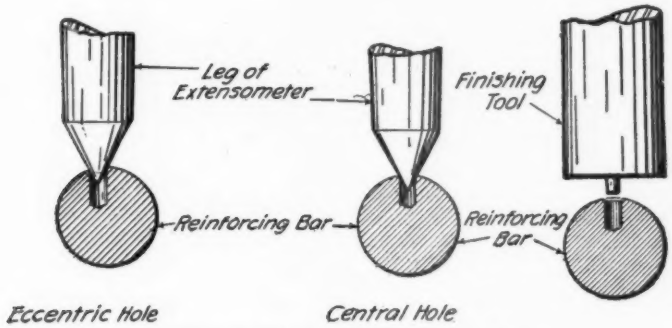


FIG. 9.—Finishing Tool and Gage Holes.

of the test. The importance of care in the preparation of holes can hardly be overestimated. It is of prime importance that the gage holes in round bars be drilled as nearly radially as possible, otherwise the readings of the strain gage may be very seriously affected by slight variations in the manner of placing the instrument in position for a reading. Fig. 9 shows a hole drilled properly and one drilled improperly. Especially in field tests of structures the proper location, drilling, and finishing of gage holes frequently involves much time, labor and inconvenience, but it must be carefully done if accurate results are to be obtained. When the readings to be taken extend over a long time the gage holes should be filled with non-corrosive grease or oil to protect the exposed surfaces, left by the drill and the

finishing tool, from rusting. For this purpose vaseline always may be obtained easily and has proved more satisfactory than oil.

In all careful tests extending over a considerable length of time, made at the University of Illinois, all strain-gage readings are corrected and adjusted for variation of temperature and of personal equation by the use of one or two standard bars. The strain gage is used as a transfer instrument between gage lines on the specimen and the gage lines on the standard bar. Two standard bars are useful in detecting any accidental variation

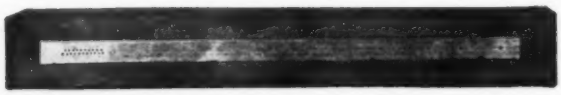


FIG. 10.—Standard Bar.

in reading of a standard bar. A standard bar adapted for use with any gage length between 4 and 11 in. is shown in Fig. 10.

To determine the multiplication ratio of a strain gage the calibration instrument shown in Fig. 11 is used. A calibration curve for the type of strain gage shown in Fig. 6 is given in Fig. 12. By means of this curve, instrument differences may be converted to change of length of the gage line in inches.



FIG. 11.—Calibration Instrument.

Fig. 13 shows the standard formulas used by the writers for reducing strain-gage readings. The "corrected difference" may be reduced to actual change of length along a gage line. This change of length divided by the gage length gives the unit change of length; the unit change of length multiplied by the modulus of elasticity of the material gives the fiber stress per unit of area along the direction of the gage line. The conditions under which the data of Fig. 14 were obtained were such that the "corrected differences" give the stress in the steel directly in thousands of pounds. If the instrument shown in Fig. 5 is

used, a plus value for "corrected difference" indicates tension; if the instrument shown in Fig. 6 is used, the reverse is true.

A universal form for recording and reducing the data of all tests in which a strain gage is used can not be given, but there is given in Fig. 14 a form (filled out with data taken in an actual test) which has proved quite generally applicable both to laboratory tests and to field tests. Examination of this sheet in connection with Figs. 12 and 13 will show the method of reduction used better than would a description of the methods.

It is quite generally advisable to exercise especial care in taking zero readings for a test since all other readings are based

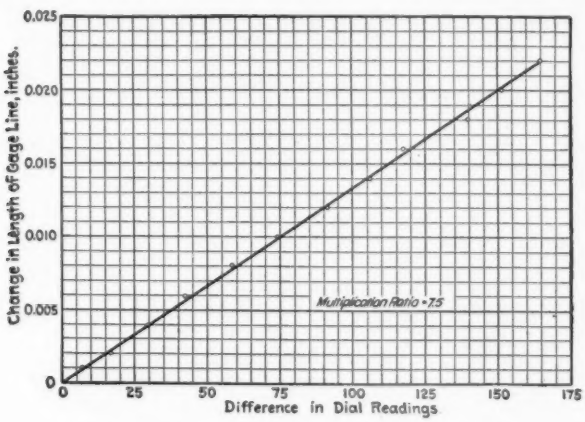


FIG. 12.—Calibration Curve for Strain Gage.

on them. Especially in field tests duplicate or triplicate sets of zero readings are advisable. Even with experienced observers it is found that the observations of the first series taken on new gage holes are less reliable than those of later series. This is shown in the following illustration. In a laboratory test involving 186 gage lines two complete series of no-load observations were taken. In these series 30 observations were found to be so discordant as to require checking, and observations were taken on these gage lines a third time. In two cases the corrected observations for the first and third series were in better agreement than those for the second and third, while in 28 cases the second and third series were in the better agreement. The explanation of

this phenomenon may be that the repeated insertion of the strain-gage points into the gage holes wears away sharp edges and burrs not entirely removed by the finishing tool. It emphasizes the necessity for taking great care in obtaining the no-load observations.

The use of the standard bar enables a correction to be made for progressive changes in readings due to changes in temperature and to other causes. The use of the standard bar also enables a correction to be made for any change in the adjustment of the strain gage itself or for a change from one strain gage

Load	Interval	0		1	2	n−2	n−1	n	
	Gage Line →	Standards a	Standards b	Arbitrary	Numbers for Gage Lines			Standards a	Standards b
Dead Load only	Uncorr Av.	S_a	S_b	R_1	R_2	R_{n-2}	R_{n-1}	S'_a	S'_b
	Correction	0	0	$\frac{1}{n}\frac{C_a+C_b}{2} = C_1$	$\frac{2}{n}\frac{C'_a+C'_b}{2} = C_2$	$\frac{n-2}{n}\frac{C'_a+C'_b}{2} = C_{n-2}$	$\frac{n-1}{n}\frac{C'_a+C'_b}{2} = C_{n-1}$	$S_a - S'_a = C'_a$	$S_b - S'_b = C'_b$
	Corr. Zero Av.			$R_1 + C_1 = A_1$	$R_2 + C_2 = A_2$	$R_{n-2} + C_{n-2} = A_{n-2}$	$R_{n-1} + C_{n-1} = A_{n-1}$		
Any Live Load, P	Uncorr. Av	s_a	s_b	r_1	r_2	r_{n-2}	r_{n-1}	s'_a	s'_b
	Uncorr. Diff.			$A_1 - r_1 = d_1$	$A_2 - r_2 = d_2$	$A_{n-2} - r_{n-2} = d_{n-2}$	$A_{n-1} - r_{n-1} = d_{n-1}$		
	Correction	$S_a - s_a = c_a$*	$S_b - s_b = c_b$*	$c_{ab} + \frac{1}{n}(c'_{ab} - c_{ab}) = c_1$	$c_{ab} + \frac{2}{n}(c'_{ab} - c_{ab}) = c_2$	$c_{ab} + \frac{n-2}{n}(c'_{ab} - c_{ab}) = c_{n-2}$	$c_{ab} + \frac{n-1}{n}(c'_{ab} - c_{ab}) = c_{n-1}$	$S_a - s'_a = c'_a$†	$S_b - s'_b = c'_b$†
	Corr. Diff			$d_1 - c_1 = e_1$	$d_2 - c_2 = e_2$	$d_{n-2} - c_{n-2} = e_{n-2}$	$d_{n-1} - c_{n-1} = e_{n-1}$		

* Let $\frac{c_a + c_b}{2} = c_{ab}$ † Let $\frac{c'_a + c'_b}{2} = c'_{ab}$

FIG. 13.—Form for Reduction of Data.

to another, if before and after such readjustment or change of instrument, readings on the standard bar are taken. The usual causes of variation in instrument readings with the strain gage are: (1) Variations in length of the strain gage caused by temperature changes arising from handling by the operator, (2) expansion or contraction of the member tested, due to temperature change, and (3) stress set up in a member by structural restriction of expansion or contraction under temperature changes. If a standard bar of Invar steel is used, the change of length of the standard bar itself under varying temperature

may be neglected (this has been confirmed by measurements made under the writers' observation); and with an Invar steel bar the corrections introduced in reducing instrument readings will be for the first only of the three causes mentioned above. If a standard bar of material similar to that in the test piece is used and the temperature of standard bar and member remains the same during a series of readings, the corrections introduced will be for the combined effects of the first two causes mentioned

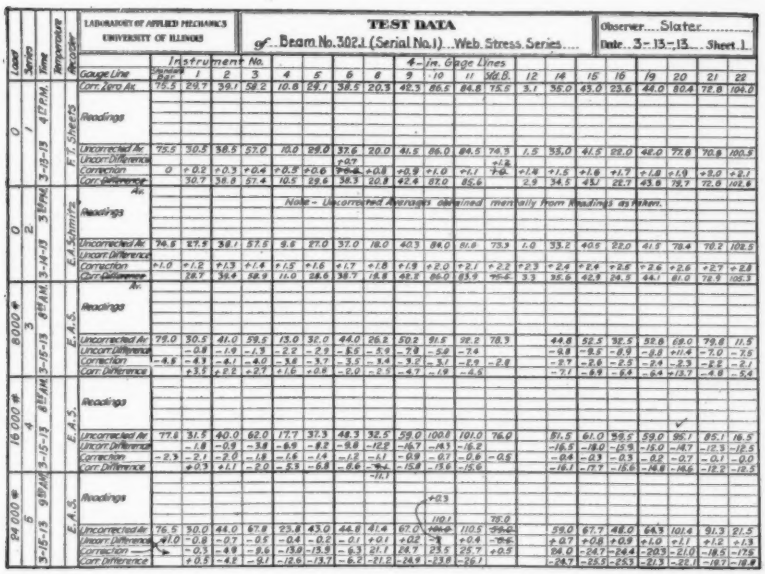


FIG. 14.—Sheet of Data from an Actual Test.

above. No simple method of correcting for the third-named cause has been devised.

The performance of the strain gage is illustrated in Fig. 15, which shows deformations measured on mild-steel bolts turned to a diameter of $\frac{1}{2}$ in. A comparison of the curves with each other shows sufficient consistency to give considerable confidence in the strain gage as an instrument of precision.

If the multiplication ratio be R, the actual change in length of any gage line is approximately 1/R times the movement of the plunger of the Ames gage. This relation is so nearly exact

mathematically that in an extreme case it is in error only about one-fourth of one per cent, hence the error may be neglected. In Bulletin No. 64 of the University of Illinois Engineering Experiment Station, "Tests of Reinforced Concrete Buildings under Load," a discussion of "Accuracy of Deformation Measurements" is given. A small portion of this discussion and the conclusion are quoted here.

"A study of probable error was made in the Turner-Carter

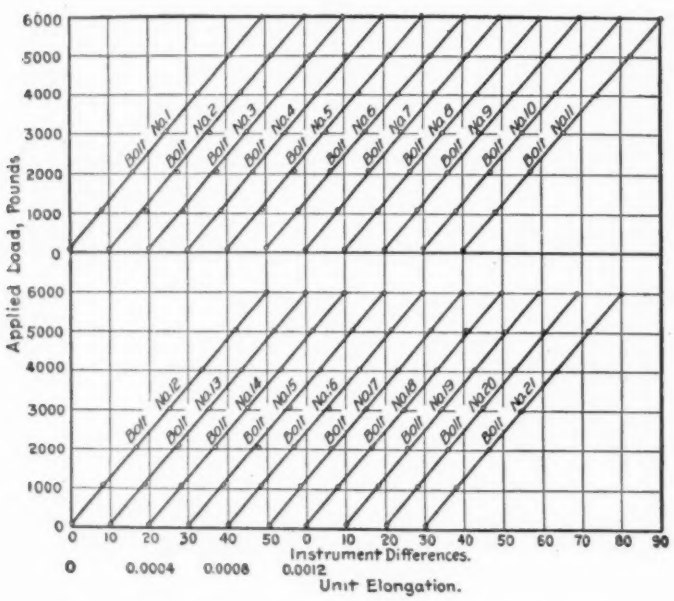


FIG. 15.—Load-Deformation Curves for ¾-in. Steel Bolts.

test (a test on the floor of a reinforced concrete building in Brooklyn, New York) by the use of a series of 100 observations taken by each of two observers on two gage lines selected as likely to give the most and the least accurate results. The results of this study are given in Table I.

"From the data in hand it seems safe to conclude that under difficult conditions stresses in steel can be determined within 500 lb. per sq. in. (plus or minus), and that under favor-

able conditions with careful work it may be determined within 200 or 100 lb. per sq. in. (plus or minus)."

The speed which may be developed in the operation of the strain gage will vary greatly with conditions of the test. In laboratory practice where gage lines are accessible and holes are well prepared, it is not uncommon for an experienced observer to take observations on 50 gage lines per hour. In a field test there frequently are many things to make the work go more slowly. The necessity of an awkward posture in observing, the necessity of removing particles of dirt from gage holes, the lack of light, and bad weather, are conditions from which few if any field tests are entirely free, and all may be encountered in a single test. As a result, the speed of observing in a field test

TABLE I.—PROBABLE ERROR OF THE AVERAGE OF ANY GROUP OF FIVE CONSECUTIVE READINGS.

	Observer.	Gage Line.		
		1	2	Average.
Unit deformation.....	H. F. Moore....	0.00000687	0.0000106	0.00000873
	W. A. Slater....	0.0000043	0.000014	0.0000091
Stress in Steel, lb. per sq. in..	H. F. Moore....	206	318	262
	W. A. Slater....	130	435	282

will vary from 50 gage lines per hour as given for laboratory tests, down to as few as 10, or possibly less, per hour. Under the conditions which usually have been met in the testing of reinforced concrete floors it seems that a speed of about 30 gage lines per hour may be expected.

The following list of tests in which the strain gage has been used, and which were made or participated in by the University of Illinois Engineering Experiment Station, is given to show the wide range of usefulness of the instrument:

Laboratory Tests.—Tests to determine flexural strength and local fiber stress in I-beams, stress distribution in short compression pieces, stress distribution in draft yokes for railway car couplers, stress in the main reinforcing rods and in the stirrups of reinforced concrete beams, stress distribution in reinforced

concrete columns, stress distribution in wide beams and slabs of reinforced concrete, deflection of curved beams, stresses in steel columns, internal stress in cold-rolled steel, stresses in steel rails.

Field Tests.—Tests to determine stresses in concrete and in steel in floor slabs and beams of reinforced concrete buildings (seven building floors have been tested), stresses in a full-size highway bridge of reinforced concrete tested to destruction, stresses in eye bars of a steel truss railway bridge.

In conclusion, the writers would state that after three years' use of the strain gage it is believed to be an instrument of a high degree of precision, if carefully used, and it has been found to be the most widely applicable type of extensometer of which they know.

DISCUSSION.

Mr. W. K. Hatt.

Mr. W. K. Hatt.—I think the advent of this movable strain gage has been a most important event in the development of the science of testing materials. It has revolutionized our testing methods. We have used it very extensively at Purdue University. Recently in a series of tests of cast-steel side frames for cars, we had 100 gage points and accurately determined deformations all over the surface of the casting. From the data the design of castings may be improved, material removed from the place where not needed and put where needed. The Berry strain gage opens up new possibilities and new fields.

Mr. Berry.

Mr. H. C. Berry.—*Definition.*—The essential feature of the Berry Strain Gage (Pat. Dec. 12, 1912) is the combination of a multiplying lever with a sensitive measuring device mounted in a frame capable of being used as a portable or hand instrument. The frame and lever are both provided with hardened steel conical points for application to prick marks or drilled gage holes in the specimen. The instrument was developed in the shop of the Civil Engineering Department of the University of Pennsylvania, under the direction of the writer. The work was undertaken because we were at that time unable to get an instrument of the type developed by Mr. J. E. Howard.

Measuring Device.—One of the earlier instruments equipped with a screw micrometer was shown at the 1910 meeting of this Society. In conversation with Mr. Moore the use of the Ames dial was brought up. Our experience with one of these instruments for other work had been unsatisfactory, though he thought very well of them. It was then agreed that Mr. Moore should construct one of these instruments for experimental work with dials and different forms of measuring devices. In December, 1910, he reported the dials to work fairly well but that "in the hands of a skilled operator the micrometer is more accurate." At about the same time we found that the dial worked very well, and that it is capable of very great speed in use. This has been confirmed by general experience since then. The dials

Mr. Berry. have given very good service and have proven much more substantial than we had at first expected.

Frame.—The earlier instruments were made with aluminum frames, but the expansion is so great that in our opinion it is a very unsatisfactory material for the purposes. We lightened the design and made use of Invar steel for the sides, and found that when used as a portable instrument there is little occasion to make any correction for the effect of the heat of the hand of the operator. With the aluminum frame 8 in. long a difference of 0.0004 or 0.0005 in. in the length of the instrument may be made by holding the hand on it for a few seconds. With the Invar instrument frequent reference to the gage will give constant readings to the nearest scale division (0.0002 in.), which gives a feeling of confidence to the observer that must be lacking in the use of the aluminum instrument.

Gage Length.—Our first instrument was intended for an adjustable gage length, but all regular instruments sent out have been for either 2 or 8-in. lengths. A special research instrument for use on reinforced concrete or steel structures is made for any length from 7 to 20 in. A very carefully made laying-off punch is used to make the prick marks into which the gage holes are drilled. It makes the holes so nearly exactly the same distance apart that the range of the instrument provides for any variation, as well as for the deformation of steel to beyond the elastic limit in either tension or compression. This in our opinion entirely eliminates any need for the slight adjustment of the gage length of the instrument provided for by the authors of the paper.

Conveniences for Use of Strain Gage.—Small pocket flash lamps clamped to the ends of the instrument by light springs have been of the greatest assistance in making readings. The small holes are quickly found, and the instrument is easily applied when the openings in the concrete are illuminated. In one test we found that we doubled the speed of the work by the use of these lamps.

We avoid the trouble found by the authors in holes that are not drilled exactly on a diameter of the rod by use of a special self-centering punch. It works on the same principle as the center square used by machinists. With it the prick

mark must be made about the middle of the rod. However we have found that in tests on flat members the results are very little affected by inclined holes. **Mr. Berry.**

The calibration of the instruments is made by the use of a special micrometer gage by which the distance from the center of the pin to the end of the finished point is measured to about 0.0005 in. Measurement is also made of the distance from the center of the pin to the ring of contact between the cone and the edge of a hole made by a No. 55 drill, which is the size we use in drilling gage points. This measurement of the levers enables us to make a number of instruments exactly alike in the value of the graduations, that is, within less than one-half a scale division. We believe this method to be better than any calibration device for actual measurement of the value of a division where such measurement may depend on a complicated apparatus, which may be in error in some of its parts.

MR. A. N. TALBOT.—I should like to second Mr. Hatt's word of appreciation of the advance in testing work which has been made possible by the development of this instrument, and to say that we are only beginning to see the applications which may be made in the determination of stresses in structures and pieces. Among the uses which have been made at the University of Illinois, is the measurement of deformation on a large number of gage lines well distributed in a test of freight-car draft yokes of various designs made for a manufacturer. The tests determined the distribution of stresses in the different parts of the yokes and threw considerable light upon the necessity for strengthening various parts of the yokes. **Mr. Talbot.**

As to gage lengths, in a recent test of eye bars on a bridge truss where there was a question on the action of loose bars, a gage length of 60 in. was used, and was found to be quite satisfactory. I want to add that the application of the Ames dial as an indicating device is what has made the instrument so useful for all these purposes. The added speed made possible through its use has increased the usefulness very much. As stated in the paper, this form of the instrument was first used in tests at the University of Illinois.

THE SECRETARY.—I too should like to second Mr. Hatt's statement. I think it difficult for any one to form an adequate **The Secretary.**

The Secretary. conception at this time of the far-reaching field of applicability of such instruments. Some three years ago a highly significant beginning was made in one important line of inquiry in connection with the construction of the cantilever bridge over the Ohio River at Beaver, Pa. In the fabrication of the principal members of that structure a large number of permanent points of contact for a strain gage were established by drilling little holes, which were filled with paraffin so as not to become incipient points of corrosion. The distances between these holes were carefully measured before the structure was erected and the temperatures were duly recorded. By similar measurements on the unloaded structure and by comparison with the corresponding measurements before erection, duly corrected for differences in temperature conditions, the actual dead-load stresses may be determined at any time and compared with the computed dead-load stresses. Similar measurements may of course be made under live loading, although such measurements are obviously more troublesome. However, for long-span bridges the dead-load stresses are apt to be the preponderating ones, and these can easily be made at any time, provided sufficient foresight has been exercised by establishing contact points before erection.

Strain-gage measurements afford an excellent means of proving or disproving the reliability of theories governing the computation of secondary stresses.

Mr. Douty. MR. D. E. DOUTY.—I should like to add a word to what the Secretary has said. At the time the Bankers' Trust Building was being constructed in New York, Mr. Howard applied his gage at the base of the four columns which carry the eleven-story tower. He conducted a series of observations there during the construction of the building, and when it reached the twenty-eighth floor, from which the tower was to begin, the engineers carefully computed the loads which the four columns were then carrying. Mr. Howard also computed two stories below, the corner of Nassau and Wall Streets, these loads from the compression at the bases, and the two sets of values checked within 12,000 lb.

Another interesting thing in connection with this building was that the trusses which were to carry the side walls on these four columns had contact points located upon them. These

were supposed to show compression in some places and tension in others. Strange to say, when the observers made the measurements, in some places where they were supposed to find tension, they found nothing, and in some places where they were supposed to find compression, they found tension. While the observations were not sufficient to define the law for the distribution of the stresses or the secondary stresses in these trusses, they were sufficient to show that the formulas upon which those stresses had been based should be revised. Mr. Douty.

MR. W. A. SLATER.—I wish to endeavor to answer only one or two of the points raised by Mr. Berry. We may find a necessity for a variable gage length arising in the character of the test we are making. For instance, we may be testing a beam which is restrained at the end. We obtain a stress curve which changes very rapidly at the support. If we use a long gage length, say 10 to 12 in., for the measurement of the stress at that position, we measure an average stress which is very much less than the maximum stress within the gage length. If, on the other hand, we use a suitable gage length for that position, say 6 to 8 in., and use the same gage length for measurement of stress at the center of the same beam where the stress possibly is much lower, we lose the accuracy of measurement required. That this may be an important item is indicated by the fact that in tests of reinforced concrete structures, we sometimes find stresses not over 2000 to 3000 lb. per sq. in. at the design load before the concrete has entirely failed in tension. For accurate measurement of such low stresses we should have a larger gage length if practicable. Mr. Slater.

Again, there are certain structures which from their physical make-up bar us from taking gage lengths of any standard size, and this renders useful an instrument which possesses elasticity as regards gage length.

Another question raised concerns the use of aluminum. The use of aluminum is merely to lighten the instrument. We sometimes have to take as many as a hundred readings in succession overhead, and in that case supporting even a small weight is very laborious, and we sacrifice accuracy of reading on account of the fatigue; but the aluminum instrument has helped to eliminate this source of error. With it, however, there is a

Mr. Slater. greater expansion of the instrument, but we have overcome this difficulty by the use of an Invar steel standard bar. In this connection, I should say that the standard bar ought to be used on almost any test, even if an Invar steel instrument be employed, because if an accident happens to the instrument and no readings have been taken on a standard gage length, it is impossible to determine the proper relation between the readings taken before and after the accident. That such accidents do not frequently happen only slightly lessens the importance of making provision for them. In our laboratory practice it not infrequently happens that during the course of a test a single instrument is used by several persons and adjusted by them for use in different places. In such cases the errors which otherwise would result from the readjustment of the instrument are eliminated by the use of the standard bar. The standard bar ought to be used anyway and the corrections can be applied as well if we use aluminum as otherwise. Other interesting points have been brought up by Mr. Berry, but I believe no more of which I should take the time to speak.

METHOD AND APPARATUS FOR DETERMINING CONSISTENCY.

By Cloyd M. Chapman.

The need of a method for the reasonably accurate determination of the consistency of neat cement paste, lime paste, cement mortar, lime mortar and concrete, has been felt for a long time. The Vicat needle has served its purpose in the testing of cement, and, with its only rival, the "ball test," has furnished the most accurate simple means of determining the consistency of neat Portland cement paste. Neither the needle nor the ball method has been successfully applied to lime paste or to mortars, and neither can be used at all with concrete. In fact, there is now no method in general use in this country for determining with any accuracy the consistency of concrete, nor is there any way in use of describing a consistency except in broad descriptive terms such as "dry," "wet," "sloppy," "mushy," etc.

In the case of cement-sand mortars using other than standard Ottawa sand, it has been customary to determine the consistency in a very roundabout way. First the percentage of water required to make a paste of standard consistency with the particular cement used is determined by the Vicat needle or by the ball method. Then, by the aid of the table prepared by the American Society of Civil Engineers, is determined the percentage of water which shall be used and a mortar is made up of a 1:3 mixture of cement and standard Ottawa sand of standard consistency. Then by making up a mixture of the sand and cement to be tested, the operator may guess when he has the same consistency as the standard sand mortar. This is a crude and uncertain method of determining consistency of mortars and only one consistency can thus be determined; but it is the one in use at the present time. In the cases of the lime pastes and mortars, and of concrete, there is no generally accepted method for determining consistency so far as the writer knows. As the necessity for test-

ing all sand to be used in important concrete work is becoming more fully realized, there is an increasing demand and necessity for a method of determining the standard consistency to which mixtures of cement and the sand to be tested shall be mixed.

Another demand for such a method arises from the increasing favor in which tests of concrete are held. Laboratory tests of concrete to determine the best proportions in which to use the available materials are becoming more common every year, and a method is needed for standardizing consistency of the mixture so that results may be more nearly duplicated and conditions reproduced.

It was with a view to finding a simple and easy, yet reasonably accurate, method of determining consistency of rather wet concrete, in order that a series of tests might be carried out under uniform conditions by several college laboratories scattered over the country, that the first trials of the method here described were made in the laboratory of Westinghouse, Church, Kerr & Co., in New York.

The method consists in depositing the mortar or concrete in a form of suitable size and shape resting on a non-absorbent surface, such as glass or metal, and then removing the form and noting the settling or sluffing down, either with or without the assistance of a jar or shock, of the unsupported mass of paste, mortar or concrete left standing.

The size and shape of the form used depends upon the consistency to which it is desired to bring the material being tested. A low form of large area being used for soft, wet mixtures and smaller, taller forms for drier mixtures.

For concrete containing coarse aggregates it is advisable to use a form at least twice the greatest dimension of the largest pieces. In case of stiff pastes, dry mortars or concrete, it is necessary to jar or shock the mass in order to produce an appreciable settlement.

A very definite consistency for a wet concrete mixture may be determined as follows: A smooth circular metal form slightly tapering from end to end, about 3 in. in diameter at the larger end, $2\frac{7}{8}$ in. at the smaller end, and open at each end, is placed on a glass plate, with the larger end down, filled with the concrete to be tested, and the top leveled off. The metal cylinder or form

is then carefully lifted and the concrete allowed to either support itself if dry enough to do so, or to settle down if wet enough to flow. The consistency desired being such that the concrete will just start to settle or sluff off when the form is lifted. If it stands erect and holds its shape without change, it is too dry. If it sinks to a heap it is too wet. If incipient settling or sinking takes place, the consistency is that sought.

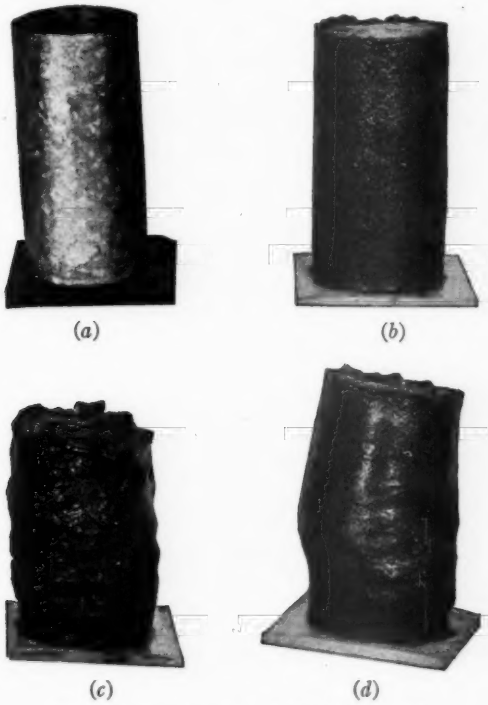


FIG. 1.—Consistency Tests of Concrete.

In Fig. 1 (*a*) is shown the only apparatus needed to perform the test; namely, a plate of glass or other non-absorbent material and a slightly tapering cylinder about 3 in. in diameter and 5 in. high.

In Fig. 1 (*b*) is shown a test in which the concrete was too dry; in (*c*), one that was too wet; and in (*d*), one that was just right.

When the desired consistency is so stiff that no flow takes place when the form is removed, or if the material under test does not readily slip out of the form, then a membrane liner is used inside the form and jarring is resorted to, in order to make the material under test settle or flow; so as to permit of measuring the amount of that flow.

The membrane used may be thin hard rubber of such size as to just line the inside of the mold. This liner is placed inside the form before it is filled. After filling and removing the form, the plate on which the test rests is lifted a definite height and allowed to fall. One of the methods by which this jarring may be accomplished is by inserting under one edge of the glass plate an object of the exact height that it is desired that the plate shall fall, and quickly withdrawing it.

The jar or shock causes the paste or mortar to settle somewhat, and so increase its circumference. This increase in circumference is indicated by a gaping open of the ends of the membrane at the joint, by a definite amount for a given consistency. If the gap is less than the proper amount, the mixture was too dry; if more, it was too wet.

In Fig. 2 (*a*) is shown the apparatus necessary for the test, namely, the metal cylinder, glass plate, liner and metal strip for jarring.

In (*b*) is shown the specimen with the liner after the form has been removed and with a metal strip inserted under the edge of the glass plate, ready to be withdrawn and allow the plate to drop.

In (*c*) is shown the specimen after the jar of falling and shows the opening of the liner due to the jar. In (*d*) is a similar test piece which was slightly too dry and therefore the opening of the liner was not equal to the required amount and in (*e*) is shown another which was too wet and therefore opened too much.

As this opening of the liner is the indicator of the proper consistency, it is desirable that ready means be provided for measuring it. This may be accomplished by making the liner or a portion of it somewhat longer than the circumference of the form and allowing the ends to lap each other. One end of the liner is marked off in equal small divisions and the other end of

the liner is arranged so as to make it convenient to read the amount of spreading near the bottom of the specimen. It is convenient also to measure the opening with a scale near the bottom. Under some conditions the liner opens somewhat as soon as the outer form is removed which makes it necessary to read the amount of this opening before jarring, and deducting it from the final reading to get the amount of movement due to the jar.

A number of materials have been tried in the search for a suitable liner for the molds. Oiled or waxed paper is satisfac-

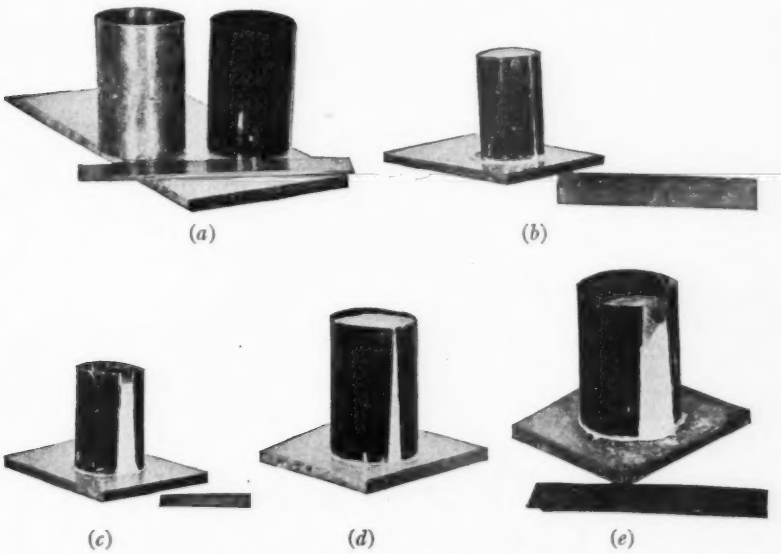


FIG. 2.—Consistency Test of Pastes.

tory with lime putty but not with cement. Thin sheet celluloid works well with lime putty and neat cement but not with cement mortar. Thin hard rubber seems to be the most satisfactory of the materials so far tried. It is smooth and flexible, is easily formed from the flat sheet into the desired cylindrical shape with the aid of moderate heat.

There are many details of the method which must be standardized for any particular consistency in any particular material or mixture. A normal neat cement paste placed in a mold

2 in. in diameter, $2\frac{1}{2}$ in. high, when dropped $\frac{3}{4}$ in., on a 4 by 12-in. glass plate, will increase its circumference, or cause the liner to open about $\frac{1}{8}$ in. An excess of water of one per cent will give an opening of greater amount, while one per cent less water will produce an opening of less amount.

There are many conditions under which it is not practical to use the very crude apparatus, shown in Fig. 2 (*a*), owing to the drop not being sufficient to jar the mass of material enough to produce the desired settling and consequent opening of the liner.

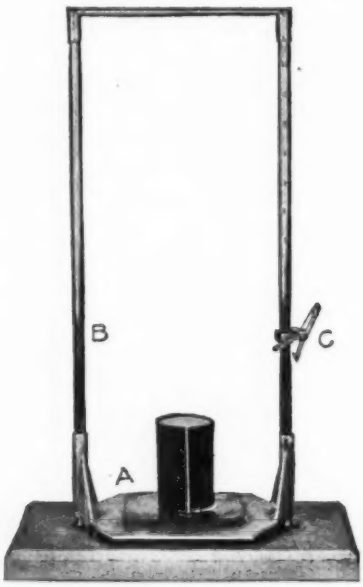


FIG. 3.

A simple apparatus has therefore been devised by means of which the specimen may be dropped from any height up to 12 in. This apparatus is shown in Fig. 3, and consists of a platen *A*, for receiving the specimen, provided with vertical guides *B*, so arranged that the platen may be raised to the predetermined height and held there by a catch *C*, on one of the guides. Releasing the catch allows the platen carrying the specimen to fall and so produce the desired shock.

The diameter and height of the specimen are details of

considerable importance. At the present time a diameter of about 2 in. and a height of 3 in. is being used for neat cement, lime putty, cement mortar and lime mortar. It may be found desirable to modify these dimensions somewhat after a wider experience has been gained in the use of the method.

Numerous tests of the method here described have been made on various materials and the results have indicated that with proper standardization it may be adapted to many of the uses for which there is at present a demand for a suitable method. It has been used in the laboratory of Westinghouse, Church, Kerr & Co., for several months in the testing of Portland cement, lime, sand, mortars and concrete.

In the standard test for Portland cement it has been found that for a neat cement paste a spreading of the liner of about 0.25 in. under a drop of 3 in., corresponds very closely with a penetration of 10 mm. of the Vicat needle. For the standard consistency of 1:3 mortar a drop of 2 in. produces an opening of about 0.25 in. With a medium stiff lime putty a 3-in. drop produces an opening of about 0.40 in., and a lime-sand mortar of rather stiff consistency gives about the same result.

The limits beyond which the method is useless are well defined in both directions, and lie between that consistency which is fluid enough to flow freely and that which is too stiff to alter its form under the influence of a comparatively light shock. The material under test must be plastic enough to conform itself to the container in which it is placed and to settle and expand in circumference under the influence of light jarring, yet it shall not be too fluid to have a tendency to maintain its form when at rest. Between these limits it is hoped the method will prove to be of some assistance in the testing of plastic materials, particularly concrete materials, and perhaps it may find some field of usefulness in the clay and other industries.

DISCUSSION

Mr. Wig. MR. R. J. WIG.—If the difficulty of measuring consistency was entirely due to apparatus in actually reading the consistency, Mr. Chapman's apparatus would undoubtedly be of some value for determining the consistency of cements; but consistency is only in part dependent upon the amount of water used, and is more dependent upon the method of mixing and the amount of work or energy that is put into the mixing, which is the one real reason why neither of our present methods are as accurate or satisfactory as they might be.

Mr. Schuyler. MR. MONT SCHUYLER.—The method described by Mr. Chapman can be modified so that it may be used in determining the consistency of plastic mortars and concretes. If the mix is placed in a cylinder, say the mold of an 8 by 16-in. concrete specimen, and the cylinder is then raised vertically a predetermined distance, the contained material will flow out to a degree governed by its consistency. A consistency number may be arrived at by measuring down from the top edge of the cylinder to the new surface of the contained material.

In tests on concrete some method such as this is absolutely necessary in order that concordant results may be obtained.

SCREEN-SCALE SIEVES MADE TO A FIXED RATIO.

By G. A. Disbro.

The size of opening, the clear space between the wires, and not the mesh, directly determines the size of product that will pass a testing sieve. For instance, by referring to a wire-cloth catalog, we find that 20-mesh wire cloth is made from 16 different diameters of wire, ranging from 0.0095 to 0.032 in. A 20-mesh sieve made from wire 0.0095 in. in diameter has an opening 0.0405 in., while a 20-mesh sieve made from 0.032-in. wire has an opening of 0.018 in. When we say "20-mesh," then, it may be any screen with 20 openings to the lineal inch made anywhere from 0.0095 to 0.032-in. wire, with a chance for variation in the sieve opening from 0.0405 to 0.018 in., a difference of 0.0225 in., so that one person may have 0.018 in. in mind when referring to a 20-mesh screen and another an opening 225 per cent larger or 0.0405 in.

In the United States, it has been common practice to use light or medium grades of wire for testing sieves, while the I. M. M. sieves are made from the heaviest wires it is possible to weave, so that the foregoing is not an exaggerated illustration of the confusion that arises from the use of the term "mesh," in reference to a sieve to be used as a standard of measure.

Most of us have given up the use of gage numbers and think in decimal sizes or the actual measure of the wire in inches. Let us take another step in advance and refer to testing sieves by the size of opening in the decimal fraction of an inch or millimeters. Instead of "20-mesh," give the opening, as "0.0328-in. testing sieve;" instead of "200-mesh product," say "0.0029-in. or 0.074-mm. product."

Let us think of our testing sieves as a series of openings. The number of meshes to the lineal inch and the size of wire to produce that opening are incidental and should be left to the wire-cloth manufacturer, so long as the cloth is of suitable grade for sifting the material. What interests us most is that the openings are uniform and accurate, and the wire cloth is double-

crimped and made from a suitable diameter of wire, so that the wires cannot shift and get out of place when the sieve is put in service.

When we consider testing sieves as a series of openings, the most important thing to decide is the relationship between these openings. For years those interested in ore dressing and the sizing of products by screens have been using testing sieves with no relationship between the sieve openings except that the openings either increased or decreased in size. It made a standard of measure without any ratio or relation between the terms of the standard. It was a makeshift, taking whatever meshes and wires that could be the most readily furnished.

Engineers will tell you that the eye is the best judge of the safety factor we have, when the object is of a size with which we are used to dealing. For instance, a man can tell instantly if a row boat is safe or not, or if a plank across a creek will safely carry his weight. It is only when the proposition is too large or too small that the eye will let us do foolish things, as building a great boat or an immense bridge that collapses almost of its own weight. If it was scaled to a size with which the eye was familiar, we would see at once the folly of the construction. So it has been with the openings of testing sieves, which are too small to have their relationship appeal to the judgment of the eye. Fig. 1 shows the opening in the Tyler Standard Screen Scale with a fixed ratio between the openings. The scale is enlarged seven[1] times and the value of the fixed ratio between the openings appeals to the eye at once. We would rebel instantly at making divisions on this rule according to the old method of openings in testing sieves having no relation to each other. In other words, we would not want a yard stick having no common relationship between its sub-divisions.

Briefly, the Tyler Standard Screen Scale is a series of accurately measured openings that increase and decrease throughout the series in a fixed ratio. The scale has as its base an opening 0.0029 in. in diameter—the opening in a 200-mesh screen made of wire 0.0021 in. in diameter, the standard sieve as

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[1] The original drawing was reduced to half size in photographing for reproduction, so that the scale as shown in Fig. 1 is enlarged only 3½ times.—ED.

adopted by the Bureau of Standards of the United States Government—the openings increasing in the ratio of $\sqrt{2}$, or 1.414.

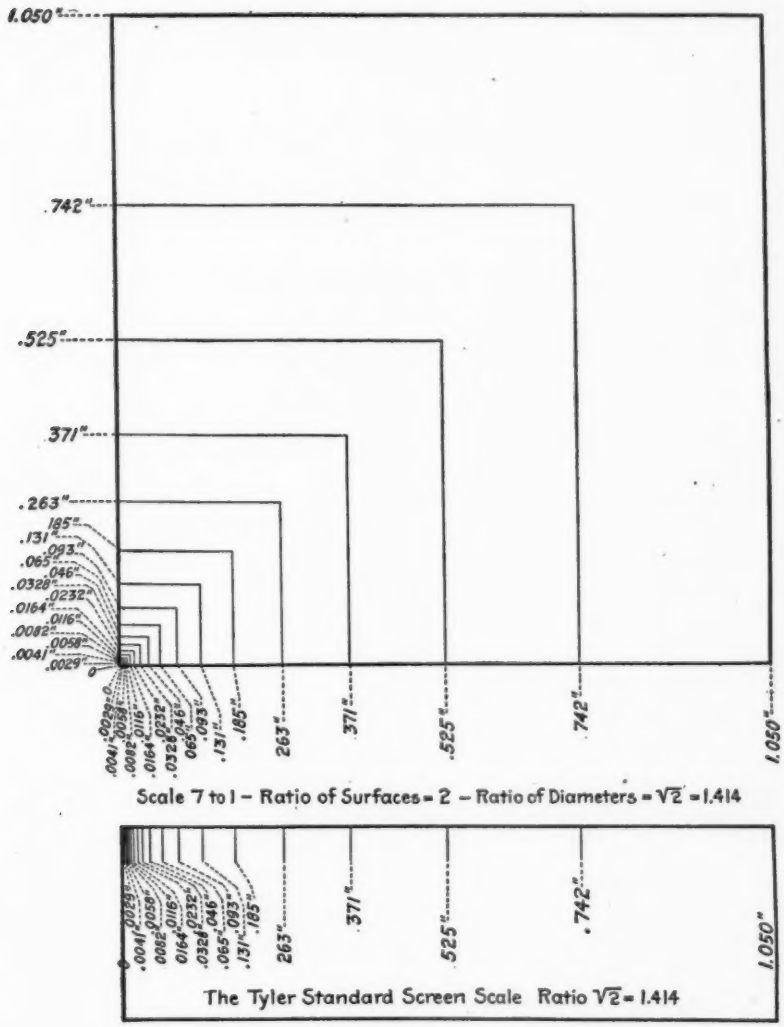


FIG. 1.

The openings in this screen scale, from 0.0029 in. (0.074 mm.) to 1.050 in. (26.67 mm.), are shown in Table I, which shows

also the mesh and wire that have been used to produce those openings.

The scale can of course be carried further for either finer or coarser screens, using the same ratio, but the table covers all the sizes generally used for laboratory work.

Let us again refer to Fig. 1 and think of this screen scale as a rule, laid out with divisions marked on it from 0.0029 in. to 1.050 in. the geometrical ratio or multiplier being $\sqrt{2}$, or 1.414. This rule, by erecting the squares for the different divisions, is both a lineal measure and a measure of squares or surfaces. It

TABLE I.—THE TYLER STANDARD SCREEN SCALE.

Opening (Ratio $\sqrt{2}$=1.414.)		Mesh.	Diameter of Wire, inch.
Inches.	Millimeters.		
1.050	26.67	...	0.149
0.742	18.85	...	0.135
0.525	13.33	...	0.105
0.371	9.423	...	0.092
0.263	6.680	3	0.070
0.185	4.699	4	0.065
0.131	3.327	6	0.036
0.093	2.362	8	0.032
0.065	1.651	10	0.035
0.046	1.168	14	0.025
0.0328	0.833	20	0.0172
0.0232	0.589	28	0.0125
0.0164	0.417	35	0.0122
0.0116	0.295	48	0.0092
0.0082	0.208	65	0.0072
0.0058	0.147	100	0.0042
0.0041	0.104	150	0.0026
0.0029	0.074	200	0.0021

is a standard of length (the diameter of the openings) and of squares (the areas of the openings).

In most screen analyses we are more generally interested in the diameter of the various size products, and for this reason we usually think of the scale as a lineal measure. The testing-sieve openings are therefore referred to by giving the diameter of the opening instead of its area.

The reasons for adopting the base and ratio shown in the screen scale may be briefly stated as follows:

Various bases have been proposed for the starting point in screen scales, some taking 1-in. and others a 1-mm. opening, the scales ranging above and below these starting points. How-

ever, as many industries have established 200-mesh cloth as the minimum in screen sizing, and as the Bureau of Standards of the United States Government has standardized the 200-mesh sieve having an opening of 0.0029 in. and made from 0.0021-in. wire, this sieve has been adopted as the base of the Tyler Standard Screen Scale.

There is also a great advantage in having as many as possible of the sizes now in general use come within the sieve series made with a fixed ratio between the openings. The sieve series outlined contains three sieves, the 0.0029-in. (200-mesh), 0.0058-in. (100-mesh), and 0.0328-in. (20-mesh), all of which come within the specifications adopted by the Bureau of Standards.

When it is necessary to carry an analysis finer than 200-mesh, sieves can be supplied as fine as 260-mesh in plain cloth and 300-mesh in twilled cloth.

The ratio between the different sizes of the screen scale has been taken as $\sqrt{2}$, or 1.414, as recommended by Rittinger in his work on ore dressing, and the niceness of this will be apparent from the following: taking 0.0029 in. or (0.074 mm.), the opening in the 200-mesh sieve as the base or starting point, the diameter of each successive opening is exactly 1.414 times the opening in the previous sieve. It also makes the area or surface of each successive opening in the scale just double that of the next finer or half that of the next coarser sieve. In other words, the diameters of the successive sizes have a constant ratio of 1.414, while the areas of the successive openings have a constant ratio of 2.

This constant ratio in the opening is shown in Fig. 1. To illustrate: the opening 0.093 in. in the 8-mesh sieve is 1.414 times the preceding opening, 0.065 in., in the 10-mesh sieve; the area of the opening in the 0.093-in. (8-mesh) sieve is twice that of 0.065-in. (10-mesh) sieve, and just half the area of the opening in the 0.131-in. (6-mesh) sieve.

Another advantage in this selection of ratio is that by skipping every other screen, the ratio of diameter is 2 to 1; by skipping two sizes the ratio is 3 to 1 (approximately); and by skipping three sizes, the ratio is 4 to 1; so that in selecting a screen scale for concentrating work, for instance, one can pick out from the table without any calculation a 1.414, 2, 3 or 4-to-1 ratio of opening.

The Tyler Standard Screen Scale with a 1.414 ratio has eighteen sieves ranging from 0.0029-in. (200-mesh) to 1.05-in. opening, making only four sieves in the series that are 0.0082 in. (65-mesh) and finer; and while this number has been found ample to cover all the requirements in ordinary laboratory practice and in the plotting of curves showing a screen analysis, yet, to provide for a closer sizing where it is necessary in the finer sizes, three intermediate sieve sizes have been added to the screen scale—0.0069-in. (80-mesh), 0.0049-in. (115-mesh) and 0.0035-in. (170-mesh). This produces a screen scale from 0.0029-in. (200-mesh) to 0.0082-in. (65-mesh), the openings in which increase in the series in the ratio of $\sqrt[4]{2}$, or 1.189, the factor recommended by Professor Richards in his work on ore dressing, or the Double

TABLE II.—RATIO = $\sqrt[4]{2}$, OR 1.189.

Opening (Ratio $\sqrt[4]{2}$ = 1.189).		Mesh.	Diameter of Wire, inch.
Inches.	Millimeters.		
0.0082	0.208	65	0.0072
0.0069	0.175	80	0.0056
0.0058	0.147	100	0.0042
0.0049	0.124	115	0.0038
0.0041	0.104	150	0.0026
0.0035	0.088	170	0.0024
0.0029	0.074	200	0.0021

Rittinger Ratio. This ratio of diameter of 1.189 makes a difference in the areas between these sizes of about 1.5 times instead of 2 as in the other scale. Table II shows the sieve openings for the closer classification, where the ratio is $\sqrt[4]{2}$. This closer ratio can be carried through the coarser sizes, if found necessary.

In the Tyler Standard Screen Scale, the size of opening has been given the place of prominence on account of its importance. The term "mesh" has been made secondary and its use should be discontinued as far as possible. In a technical sense, the word "mesh" is meaningless, unless the diameter of the wire is also given so that the opening can be determined. The size of opening is the measure of the product and the mesh and diameter of wire are only valuable as a means of determining the size of opening.

The fallacy of indicating sieve openings by mesh instead of the actual size of opening in inches or millimeters is clearly shown in the screen scale. For instance, from 100-mesh to 200-mesh, a difference of 100 meshes, there is only a difference in sizes of openings from 0.0058 to 0.0029 in., or 0.0029 in., while from 3-mesh to 48-mesh, a difference of only 45 meshes, there is a difference in sieve openings from 0.263 to 0.0116 in., or 0.2514 in. In other words, the sieve openings only double in 100-mesh in the fine sizes, while in the coarse sizes, the sieve openings increase 23 times in size with a difference of only 45 meshes. On sieves made to the Tyler Standard Screen Scale will be found name plates marked with the size of opening both in inches and millimeters, and showing also the number of mesh.

The value of a standard with a fixed ratio between sieve apertures, to which all can work, with reference to comparing the results of tests of one individual with another, is admitted. Other scales have been worked out but they did not lend themselves to practical and economical manufacture of the sieve cloth, while the one here described commends itself to both use and manufacture. With this in mind, the adoption of such a screen scale by this Society would contribute materially to the advancement of standardization in technical work.

GRAPHIC ILLUSTRATION OF SCREEN ANALYSIS.

Not only do the screen-scale sieves divide a product in much better proportion than a sieve series without any relationship between the openings, but the results of the screen analysis can be represented by a plotted curve to much better advantage.

There are many advantages in the graphic method of illustrating the data obtained in a screen analysis. Plotted curves of the crushings by different methods or from two competing machines, for instance, express the difference in a more striking and concise manner than do the tabulated data. Of the several methods of plotting these curves, the cumulative direct plot and cumulative logarithmic plot are the two most valuable and generally used. The curves by either method are plotted by marking the cumulative percentages of the material which remain on the sieves as ordinates on vertical lines drawn from the several corresponding openings on the horizontal scale of the diagram.

After drawing in the curve, the percentages remaining on any set of openings other than those of the testing sieves used can be found by interpolation, and in this way the redistribution of the same material by any assumed set of openings can be determined without having sieves of those openings. By cumulative percentage is meant the total amount of the product which would remain on a testing sieve if only one sieve were used for testing the whole sample, so that to get the cumulative weight, it is necessary to add all of the material which remains on sieves coarser than the one in question to the amount remaining on that sieve. In other words, each point on a cumulative plot represents the total material that would be retained if only the one sieve represented by that particular point were used in the analysis.

The difference between a direct and logarithmic diagram is that in a direct plot the sieve openings are laid out to an arithmetical scale, while in the logarithmic plot they are laid down to a logarithmic scale. That is, in the arithmetical scale the actual horizontal distances between each vertical line increase or diminish in the same ratio as that in which the screen openings increase or diminish; in the logarithmic scale, the screen openings are plotted to the logarithm of the diameter of the opening and since the ratio between the sizes is a constant, the horizontal scale of screen openings will be one of equal spaces.

Specially ruled paper has been prepared for plotting these curves. The size of the sheets are $8\frac{1}{2}$ by 11 in. and of suitable paper for making blue prints. On them are printed the Tyler Standard Screen Scale with blank columns for noting the weight of the material remaining on each testing sieve, the percentage of weight, and the cumulative percentage of weight. (See Tables III and IV.)

Cumulative Logarithmic Plot.—The arithmetical difference between the size of openings in the standard screens is small for the fine sizes, while for the coarser screens the arithmetical difference is comparatively great. However, the ratios between the size of openings in successive sieves are constant, and it is the ratios that are usually considered in commercial screening. A very satisfactory way to plot a curve covering a wide range of sizes is to represent equal ratios of diameter by equal distances,

thereby compressing the curve for the coarse sizes and extending it for the small sizes. This result is secured automatically by plotting the logarithms of the diameters of the openings on the horizontal scale.

Fig. 2 shows the cumulative logarithmic plot on the "inch scale" of the screen analysis recorded in Table III. Such a test could also be plotted on a "millimeter scale." It will be observed that the logarithmic interval between 0.001 in. and 0.01 in. is the same as that between 0.01 in. and 0.1 in. or between 0.1 in. and 1.0 in.

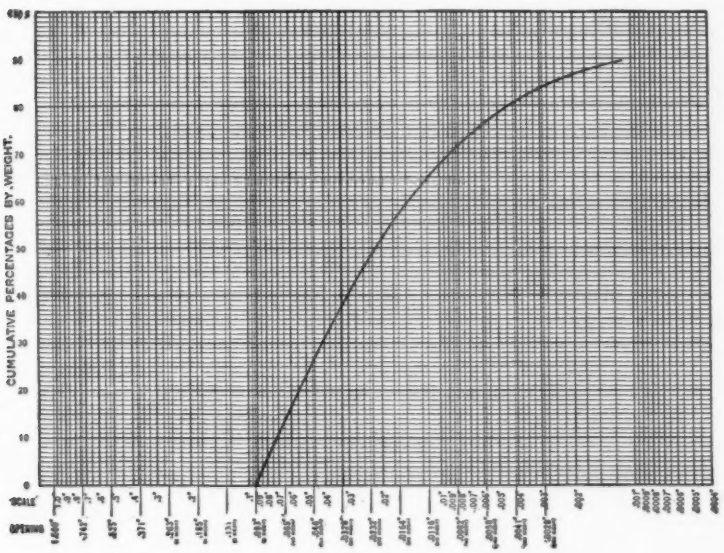


FIG. 2.—Cumulative Logarithmic Plot.

The unit lines are heavier than the fractional lines. Where the space between the units is small, as between 0.04 in. and 0.05 in. or 0.05 in. and 0.06 in., there is room for only one fractional line; but where the space is greater, as between 0.01 and 0.02 in. or 0.02 in. and 0.03 in., three fractional lines are shown dividing the space into quarters, as 0.0125, 0.0150, 0.0175 and 0.020 in. or 0.0225, 0.0250, 0.0275 and 0.030 in. The lightest vertical lines indicate the correct position of the sieves of the Tyler Standard Screen Scale. It is a very easy matter to point the cumulative

percentage on the light lines which indicate the sieves and then draw in the curve.

To make this method of plotting perfectly clear, it should be pointed out that although the logarithmic spacing is not the same as the arithmetical difference between the numbers, yet for short intervals the variation between the two is too small to be noticed; for example, 0.120 in. is located with practical accuracy on the paper by taking a point eight-tenths of the distance from 0.1 to 0.125 in. $(0.8 \div 0.025 = 0.020)$. For a longer

TABLE III.—SCREEN ANALYSIS SHOWING CUMULATIVE PERCENTAGES.

Indicate the Screen Crushed through and also First Retaining Screen.	SCREEN-SCALE RATIO 1.414.				WEIGHTS.		
	Openings.		Mesh.	Diameter of Wire, inches.	Sample Weights, grams.	Per Cent.	Per Cent Cumulative Weights.
	Millimeters.	Inches.					
	26.67	1.050	...	0.149	.....	....	....
	18.85	0.742	...	0.135	.....	....	....
	13.33	0.525	...	0.105	.....	....	....
	9.423	0.371	...	0.092	.....	....	....
	6.680	0.263	3	0.070	.....	....	....
	4.699	0.185	4	0.065	.....	....	....
	3.327	0.131	6	0.036	.....	....	....
All Pass.....	2.362	0.093	8	0.032	.....	....	....
Retained On.....	1.651	0.065	10	0.035	70.0	14.0	14.0
" "	1.168	0.046	14	0.025	60.0	12.0	26.0
" "	0.833	0.0328	20	0.0172	50.0	10.0	36.0
" "	0.589	0.0232	28	0.0125	55.0	11.0	47.0
" "	0.417	0.0164	35	0.0122	50.0	10.0	57.0
" "	0.295	0.0116	48	0.0092	35.0	7.0	64.0
" "	0.208	0.0082	65	0.0072	30.0	6.0	70.0
" "	0.147	0.0058	100	0.0042	32.5	6.5	76.5
" "	0.104	0.0041	150	0.0026	20.0	4.0	80.5
" "	0.074	0.0029	200	0.0021	17.5	3.5	84.0
Pass.....	0.074	0.0029	200	0.0021	80.0	16.0	....
Totals.....	.....	.....	.....	.....	500.0	100.0	.....

interval, however, as from 0.1 to 0.2 in., it would not be sufficiently accurate on the logarithmic scale to locate 0.15 in. as half-way between 0.1 and 0.2 in.

Cumulative Direct Plot.—Fig. 3 shows a cumulative direct plot of the screen analysis given in Table III. This form of direct plotting is unique, since all crushings, to whatever size, are expressed on diagrams of the same uniform dimensions and having the same length of base line. This renders a comparison of the curves from various crushings more comprehensive than when diagrams with varying lengths of base line are used.

The vertical lines on the diagram represent any given set of sieve openings having a constant ratio of 1.414, the first left-hand vertical representing the screen opening through which the sample has all been crushed, and the last or extreme right-hand vertical, representing zero. The curves, therefore, start at the lower left-hand corner and terminate at the upper right-hand one.

Thus, in the test plotted, the material was reduced with rolls to all pass an 0.093-in. (8-mesh) opening; hence the extreme

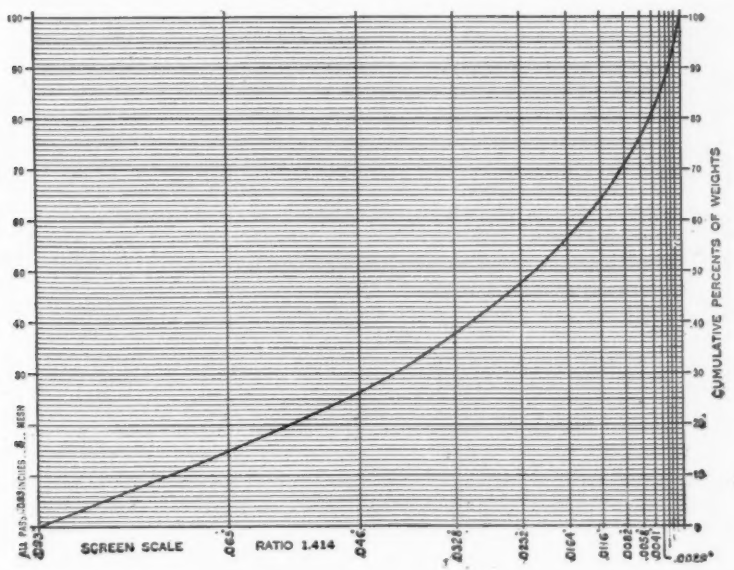


FIG. 3.—Cumulative Direct Plot.

left-hand vertical is marked 0.093 in., the next 0.065 in., etc. Eleven screens were used in this analysis, which are represented by the use of the same number of vertical lines on the diagram, and are so designated by the written figures. The intersection of the 0.0029-in. (200-mesh) vertical with the curve shows that the cumulative (or total) percentage of material held on this size was 84, leaving 16 per cent as the amount passing through, which is represented by that portion of the curve lying to the right and beyond the 0.0029-in. intersection. Likewise the

0.0328-in. (20-mesh) vertical cuts the curve at 36 per cent, the amount retained on that sieve, leaving 64 per cent as the amount passing through that size opening.

However, had the crushing been for instance through 0.0164 in. (35-mesh), and consequently only six screens used in the analysis, then the sixth vertical would be used to represent the last or 0.0029-in. sieve in the series, instead of the eleventh as in the previous case.

After some experience with this method, the curve corre-

TABLE IV.—SCREEN ANALYSIS OF CONCENTRATOR MILL HEADS.

Indicate the Screen Crushed through and also First Retaining Screen.	SCREEN-SCALE RATIO 1.414.				WEIGHTS.		
	Openings.		Mesh.	Diameter of Wire, inches.	Sample Weights, grams.	Per Cent.	Per Cent. Cumulative Weights.
	Inches.	Millimeters.					
	1.050	26.67	...	0.149	....	.....	.....
	0.742	18.85	...	0.135	....	.....	.....
	0.525	13.33	...	0.105	....	.....	.....
	0.371	9.423	...	0.092	....	.....	.....
	0.263	6.680	3	0.070	....	.....	.....
All Pass.....	0.185	4.699	4	0.065	....	.....	.....
Retained On.....	0.131	3.327	6	0.036	253	12.65	12.65
" "	0.093	2.362	8	0.032	264	13.2	25.85
" "	0.065	1.651	10	0.035	262	13.1	38.95
" "	0.046	1.168	14	0.025	155	7.75	46.70
" "	0.0328	0.833	20	0.0172	133	6.65	53.35
" "	0.0232	0.589	28	0.0125	126	6.3	59.65
" "	0.0164	0.417	35	0.0122	94	4.7	64.35
" "	0.0116	0.295	48	0.0092	83	4.15	68.5
" "	0.0082	0.208	65	0.0072	66	3.3	71.8
" "	0 0058	0.147	100	0.0042	64	3.2	75.0
All Pass 0.0058 in.	.....	.....	...	.....	500	25.0	.....
Totals	.....	.....	...	.....	2000	100 0	.....

sponding to any given material, size, or method of crushing can be very closely approximated, and from it an estimate of the different size quantities made without recourse to, or in the absence of, any laboratory experiment on the ore.

To illustrate the usefulness of the plotted curve, let us take an illustration from actual practice. Given a sample of concentrator mill heads, which are the undersize of trommels equipped with 3-mesh, 0.148-in. wire, opening 0.185 in. According to the arrangement of the mill, these mill heads pass successively through three sets of trommels, the oversize of which is delivered to three sets of jigs, while the undersize of the last trommel passes to tables and vanners. With the last of the three

trommels equipped with 12-mesh, 0.047-in. wire, opening 0.036 in., with what size of screen openings should the other two trommels be equipped to divide the jig product evenly by weight between the three sets of jigs?

The screen analysis of the product passing the 3-mesh, 0.148-in. trommel is shown in Table IV. It has only been carried as fine as the 0.0058-in. (100-mesh) sieve, since we are not interested in the fines which go to the tables. After plotting

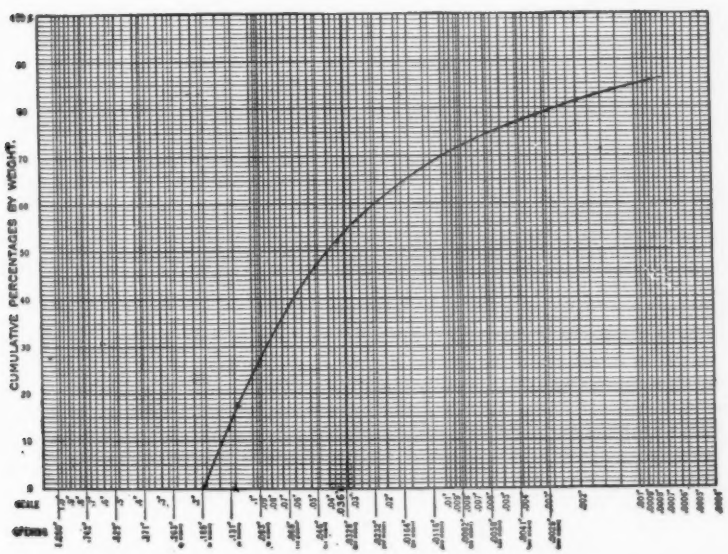


FIG. 4.—Curve Showing Screen Analysis of Concentrator Mill Heads.

the curve (Fig. 4) showing this screen analysis, we find that the opening 0.036 in. (the 12-mesh, 0.047-in. wire on the last trommel) will retain 52.5 per cent of the product, which is the amount to be divided equally by weight between the three sets of jigs. One-third of this amount is 17.5 per cent. By finding the point on the curve representing 17.5 per cent of the product, we see that this part of the material will be retained by an opening of 0.125 in.; the position of the point on the curve representing 35 per cent of the product indicates that an opening of 0.0725 in. will retain that percentage of the product. Therefore, to divide

the product equally on the three jigs the first trommel must be covered with a screen that will retain the 0.125-in. part of the ore, and the second trommel with a screen that will retain the 0.0725-in. part of the ore. It is then an easy matter to select the required style of screen to produce this result. Fig. 5 shows a diagram of the trommels and jigs with the distribution of the product. From this it is easy to see the value of the plotted curve in the redistribution of a crushed product on any assumed set of openings.

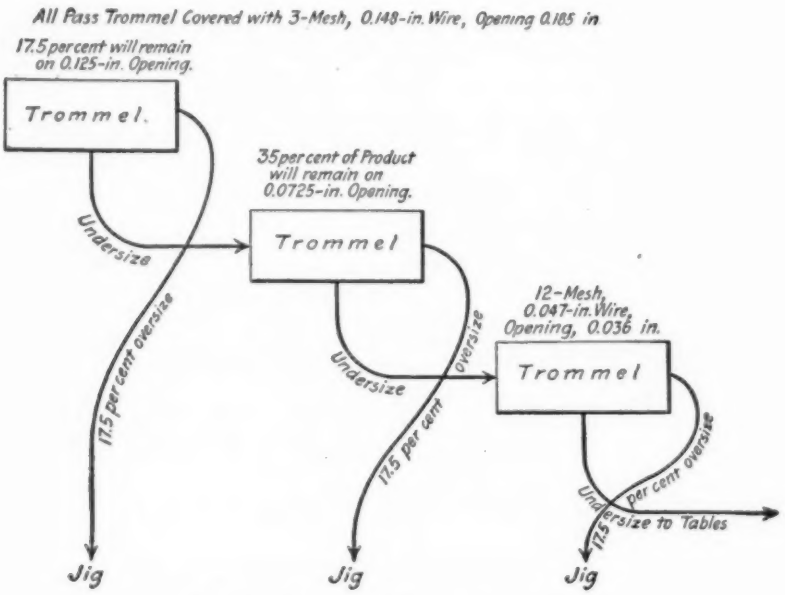


FIG. 5.—Diagram of Trommels and Jigs.

OTHER SUGGESTED SERIES.

Just a few words as to some of the suggested scales. Although several screen scales have been proposed from time to time, they have never found their way into common use or practice. This was on account of the difficulties of weaving the many odd sizes of mesh and wire called for in the proposals, and also of the fact that the screens scales did not contain the sieve openings in general use.

Institute of Mining and Metallurgy Series.—In 1907, the Committee on Standards of the Institute of Mining and Metallurgy, adopted a sieve series for laboratory use. The main idea in this series seemed to be the manufacture of the screens in such a way that the wires could not get out of place, having about 25 per cent of the screen as opening and the rest dead surface. They figured that if the size of wire was made the same size as the screen opening, the wires would have no chance to shift. This, however, is not true, for if screen is made single-crimped, no matter how heavy the wires are they can shift and slide on the straight wire; whereas if the screen is double-crimped, the wires will not get out of place even though the screen is made from much lighter wire. As a result, this sieve series is composed of screens made from extremely heavy wire, such as would be more suitable for clothing a trommel screen or jig than for covering testing sieves. In the finer sizes, the wire specified was so heavy that it was impossible to construct a double-crimped screen with accurately measured openings to their specifications. The diameter of a testing sieve is naturally limited and there is an advantage in having as large a percentage of screening surface in the sieve as possible. Consequently, it is better to use a light or medium weight of wire, heavy enough to allow a double-crimped construction that will keep the mesh uniform in size until the screen is worn out.

The greatest objection, however, to this sieve series is that there is no relation or fixed ratio between the various sieve openings in the series. The only law followed is that the openings are constantly increased or decreased in size, therefore the I. M. M. sieve series is not a regular one.

Cube Root Series.—Mr. T. J. Hoover proposed the use of a geometric series of screen openings, starting with a 1-in. opening, the successive screen openings being obtained by dividing the preceding opening by the cube root of three. The novel feature of this scale was that it harmonized the English inch and the metric millimeter, for the fifteenth sieve had an opening of 0.03937 in. or one millimeter.

Inasmuch as the sieve series started at 1 in., the one standard contained both the English inch and the millimeter, so that the sieve series could be said to start either with the inch or

millimeter and work both ways. The objection to the series, however, was that it was impossible to work out a series of meshes and sizes of wire which would produce the necessary sieve openings without going to an enormous expense in equipping special machinery for the work. Another objection to the series was that it would not contain any of the sieves in general use. This cube root series had been previously suggested by Prof. Robert H. Richards, but he did not advise its use.

Rittinger Series.—Rittinger proposed a geometric series in which the ratio between the size of aperture between the successive screens was $\sqrt{2}$, his first screen being 1 mm. An objection has been raised to this series on the basis that there were not enough numbers in the fine sizes, while the series would work out very nicely for the coarse sizes.

Richards Series.—Professor Richards proposed a geometric series in which the ratio between the sieve openings was $\sqrt[4]{2}$ and his first term 1 mm. This series might be referred to as a double Rittinger series. The advantage of this series is an increased number of sieves in the fine sizes, but it makes too many sieves in the coarser sizes.

In the Tyler Standard Screen Scale Series, a compromise has been made by using the Rittinger ratio from 0.0029-in. opening to 1.050-in. opening, making eighteen sieves in the series. Then where closer sizing is required, the Richards ratio has been used.

EXTRACTOR FOR BITUMINOUS PAVING MIXTURES.

By C. N. Forrest.

Suitable methods for the examination of bituminous paving mixtures containing a mineral aggregate of broken stone are of greater interest to analysts at the present time than formerly, on account of the extensive use of such mixtures in the improvement of country highways.

One of the first considerations in the analysis of a paving mixture is the separation of the bituminous binder, which may be of an asphaltic character or a tar, and various types of apparatus have been proposed for this purpose from time to time, such as centrifuges and extractors of the Soxhlet, Wiley and other types. The chief difficulties in the operation of such apparatus lies in the fact that a large quantity of the paving mixture is required if the stony particles are as large as one inch, which is usually the case so that the sample may be representative, and in the safe handling of such a normally disagreeable and dangerous substance as carbon disulphide, which is the solvent best suited and is usually required for the purpose.

Mixtures containing a coal-tar binder can only be extracted successfully with a hot solvent, and in any event a hot extraction is always more quickly accomplished than a cold one.

Following the general principle of the well-known Wiley extractor, the device illustrated in Fig. 1 has been developed and installed in the New York Testing Laboratory for use in the analysis of coarse aggregate paving mixtures, such as asphalt blocks, asphaltic concrete and bituminous macadam.

A battery of six of these devices, installed as illustrated in Fig. 2, easily permits of the analysis of at least a dozen samples of mixture in an eight-hour working day.

Five hundred grams of mixtures containing stone coarser than $\frac{1}{2}$ in., or 300 g. of mixtures finer than $\frac{1}{2}$ in., are closely packed in the wire basket and covered with a disk or wad of absorbent cotton or felt.

From 175 to 200 cc. of carbon disulphide, carbon tetrachloride, benzole or chloroform are placed in the inside vessel, in which the wire basket is also suspended.

Cool water must be circulated through the inverted conical condenser, which also is the cover of the extractor and is not intended to fit tight.

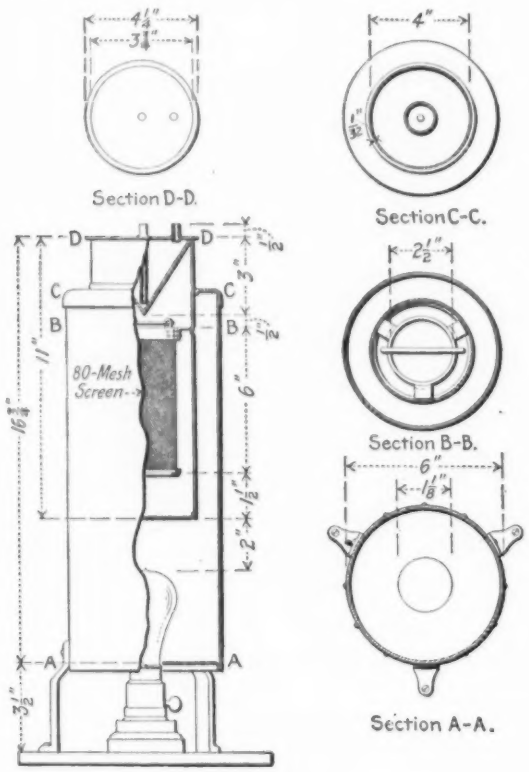


FIG. 1.

A 16-candle-power incandescent carbon filament bulb is the source of heat.

Complete extraction of the bituminous binder may be accomplished in three hours, without appreciable loss of solvent or any of the disagreeable results accompanying the use of some of the centrifugal type extractors.

Fine mineral matter which passes through the meshes of the wire basket may be recovered in the customary way of burning the entire extract in a platinum or other suitable dish, or by making such a correction after first recovering a large portion of the solvent by distillation. On account of the danger from fire in distilling carbon disulphide in glass apparatus, such is not a safe procedure, and we have abandoned any attempts at extreme economy in handling that highly inflammable solvent.

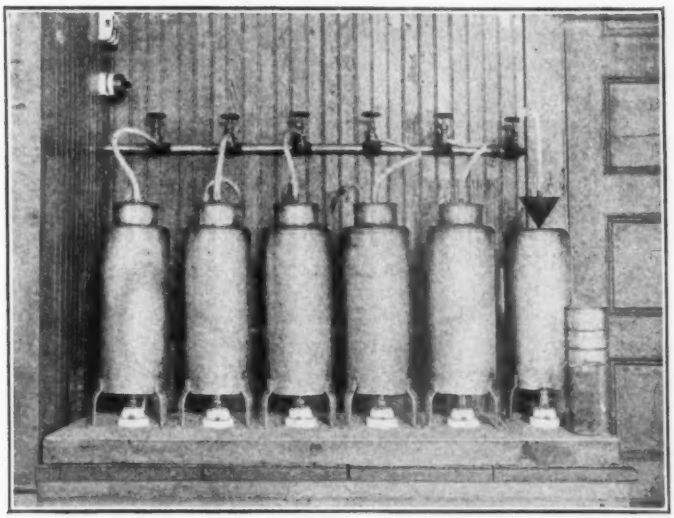


FIG. 2.

The amount of the correction will vary from 0.10 per cent, in the analysis of coarse macadam mixtures, to 1.0 or 2.0 per cent, in the analysis of asphalt blocks which contain 15 per cent or more of 200-mesh dust.

On account of the very delicate character of wire cloth finer than 80 mesh, it has not been found practicable to employ a finer mesh cloth for the baskets. Otherwise the device is practically non-breakable, as it is constructed of brass throughout.

CONSERVATION AND SHIPPING CONTAINERS.

By B. W. Dunn.

From statistical reports of the Interstate Commerce Commission it is estimated that an annual loss to our national resources of not less than thirty millions of dollars is sustained through damage to railway freight. The magnitude of this loss and the fact that millions of our fellow citizens are vitally interested in minimizing it, insures the attention of this Society for any reasonable comment.

Among the prominent causes we recognize theft, insecure packing, illegible and incorrect marking, rough handling of packages in cars and improper loading of freight into cars. We are to give special attention to the advisability of standardizing specifications for shipping containers with a view to minimizing the losses that are due to insecure packing.

Common carriers have always had a legal right to specify the packing required for different kinds of freight; but for two reasons their specifications have not been sufficiently explicit and rigid. They have not had enough data to make them explicit, and the competition of rival lines for freight has not promoted rigidity in packing requirements. It is plain that by the unrestricted acceptance and movement of large quantities of freight we can create conditions similar to those that would attend the movement of a large mob of men as distinguished from the movement of a military organization. To transform the mob, however, we must have time to instruct and drill it, while in the movement of freight the carrier is always confronted by the danger of congestion. About 70 per cent of the day's offering of freight at a large railway station is received in the late afternoon, in less than 30 per cent of the day's working hours. During this rush period the receiving clerks are barely able to verify the shipper's list of packages and no time is available for a critical examination of these packages to discover defective containers. Add to this the natural contention of railway traffic officials that revenue-bearing freight should not be refused

under any circumstances, and it is plain that the carrier is not well protected against the shipper who is willing to reduce the cost of his shipping container at the expense of its efficiency.

The demand of the same shipper for quick service, and railway competition to furnish it, contribute to the hurried loading of these packages into cars without due regard to the destructive pressures to which the packages will be subjected when the same rush conditions control the switching and classification of these cars into main-line freight trains. The carrier's struggles against freight congestion have developed the automatic coupler, the gravity track or "hump" and the steel-underframe freight car. The effect is to reduce from minutes to seconds the time required to move and group these cars on specified tracks and to increase correspondingly the severity of the shocks incident to this rapid disposition. The steel-underframes will stand the shocks and the trainmen do not see, as a rule, the effect on the packages in the car. It is useless to suggest as a remedy that we avoid all shocks to cars. Some increase in the roughness of handling cars is a natural development in the struggle against congestion of freight.

It is intended by this rough sketch of the prevailing conditions to show that the transportation and shipping interests have an important mechanical problem to solve. What is a reasonable limit to the speed in miles per hour at which a freight car should be permitted to collide with other cars in switching movements? The answer must recognize the conditions that require the classification of a large number of cars in a limited time. What pressures tending to injure the car and its lading will be generated by the blow due to this impact? How far is it practicable to go in specifying the resistance that a shipping container must offer to resist these pressures successfully?

To couple cars carefully, the speed should not exceed two miles per hour at the instant of collision. This limit was not observed with any degree of uniformity even when hand-operated couplers were in use. Friction draft gears, now used almost to the exclusion of the old spring buffers, are constructed to absorb about 18,000 ft-lb. of energy each, or 36,000 ft-lb. for the two gears involved in any impact. This energy is furnished

by a loaded freight car weighing 150,000 lb. and moving at a speed of 2.68 miles per hour. For any speed in excess of this the additional energy must be absorbed by the elastic, or permanent, deformation of the car frame. The draft-gear energy limit of 36,000 ft-lb. restricts the coupling speed for an empty freight car of average weight to about five miles per hour. Tests made with such a car have shown that for this speed the maximum retarding pressure caused by coupling is not less than five pounds per pound of weight retarded.[1] This pressure is exerted on the packages of freight in the car as well as on the car itself. When a column of packages occupies the entire length of the car the pressure on the end package for a coupling speed of five miles per hour may exceed five times the total weight of the column of packages. When these packages are free to slide along the car floor the coefficient of friction will be high and a path of from two to three feet may suffice to absorb the energy corresponding to a speed of five miles per hour. This frictional resistance is not a practical remedy, however, since the average car receives many successive shocks. When we consider the magnitude of the pressures that may be exerted so readily on these packages under normal conditions, it is not surprising that the total of the annual damage claims runs into many millions.

Figs. 1 to 9 show defective packages in transit that are not as exceptional as they should be. Hundreds of similar ones could be collected in a few days at any large transfer station. There are at least three general types of non-metallic boxes: wooden, wirebound veneer, and fiberboard. Conclusive arguments as to the relative inefficiency of these types cannot be drawn from illustrations taken at random. It is safe to assume that many such illustrations could be obtained for each type.

When we seek a remedy we must recognize among the contributing causes several independent factors calling for separate treatment.

Some of the men employed by the railways to handle freight cars are criminally careless and indifferent. They work frequently at night and at isolated points where direct and constant supervision of them is practically impossible;

[1] See "Measurement of Impact Stresses." *Proceedings*, Am. Soc. Test. Mats., Vol. IX, p. 650 (1909).

and they belong to labor unions that are credited with resisting unreasonably, but successfully, the disciplining of their members. The development and use of a reliable and efficient time and shock-recording instrument would help to prove their delinquencies in handling cars roughly. An extended educational campaign, persistently followed, should secure the cooperation of the better and more numerous class of trainmen and the exercise of their influence over their careless and indifferent members. An extract from the last quarterly bulletin of the Bureau of Explosives illustrating educational efforts of this nature is given in Appendix I.

When packages of explosives, in special containers many times stronger than the average shipping container for the same weight of ordinary merchandise, are broken by rough handling of cars that occurs in spite of special Federal regulations prepared and issued to protect dangerous freight, it is reasonable to assume more extended damage to ordinary freight. Not only in the unnecessary rough handling of freight cars does the exceptionally careless trainman contribute to this destruction of property. The same man will frequently be found dropping heavy or fragile packages from car doors where no unloading platform exists. Some of the responsibility for this and similar acts of vandalism can be placed with the superiors of the trainmen if they fail to supply him with skids and other appliances necessary to unload these packages properly. It is a favorite subterfuge of shippers proven to be the users of insecure shipping containers to excuse themselves on the plea that no package can be made strong enough to stand railway treatment of it. Destruction by railway men exists but it is exceptional, while the user of a defective package is a constant source of trouble and loss.

A shipper should present his shipment to the carrier in a container that will protect its contents against injury under normal conditions. What normal conditions are must ever remain a matter of opinion and good judgment based upon all available facts. It is not wise to strain any material beyond its elastic limit, and the path required to absorb the energy of a colliding freight car ought not to exceed that afforded by the friction draft gear. There is a distinct advantage in permitting

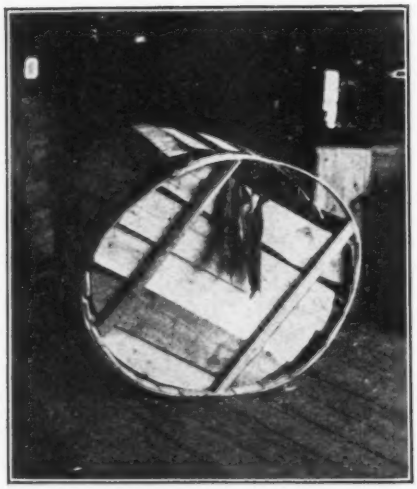


FIG. 1.—Hogshead of leaf tobacco weighing 1400 lb., made of staves only ½ in. thick without grooves, head being held by battens only. Shipped from Kenbridge, Va., to Richmond, Va.



FIG. 2.—Station carpenter trying to reassemble the broken pieces of a cast-iron stove and its flimsy wooden crate. Shipment moving from Richmond, Va., to Elizabeth City, N. C.



FIG. 3.—Two pieces of antique mahogany furniture moving from Meyers, Fla., to Woodside, Del.



FIG. 4.—Dry goods shipped from New York City to Richmond, Va.

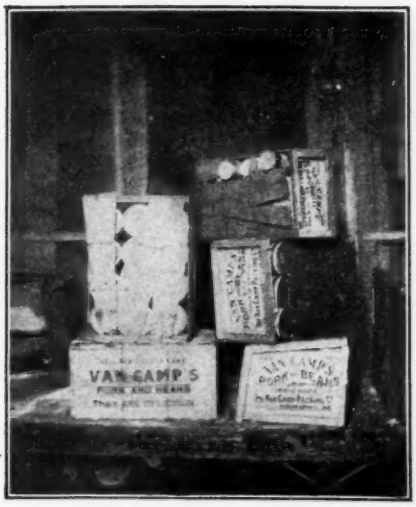


FIG. 5.—Case of pork and beans moving from Martinsville, Ind., to Richmond, Va.

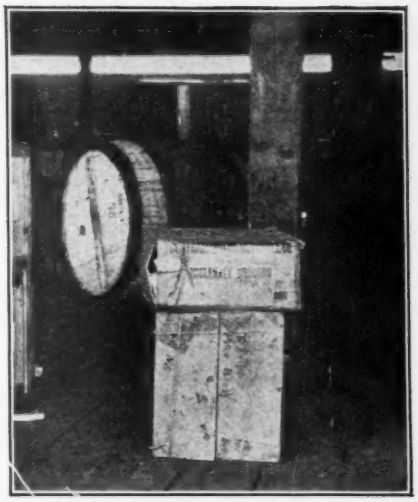


FIG. 6.—Groceries and matches in fiberboard boxes, moving from Cleveland, Ohio, to Pine Bluff, Ark. Photograph taken at St. Louis, Mo.



FIG. 7.—A shipment of cloth caps in a large box made of boards only ⅛ in. thick, moving from Baltimore, Md., to Richmond, Va.

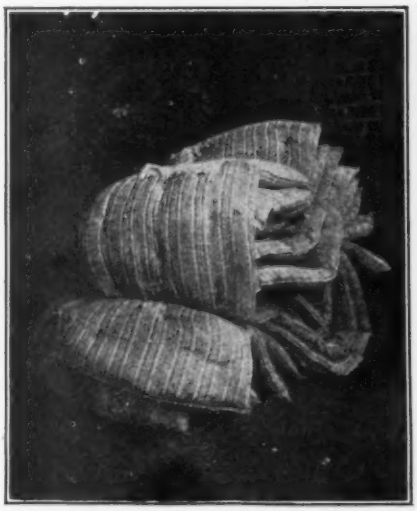


FIG. 8.—A shipment of mattresses without any burlap protection and refused by consignee on account of stains received while in transit.

the coupling speed for the average car to be as high as the draft gear will permit, as this will facilitate prompt movement of cars and delivery of freight. Let us assume by way of illustration that the maximum limit for this speed is placed at four miles per hour and that the maximum pressure on a package of freight in the end of the car due to this shock is four times the total weight of the column of packages in the length of the car; then the shipper should furnish a package capable of standing this pressure with a reasonable factor of safety. His freight may consist of material that can stand this pressure without the protection of a container, or the strength of the

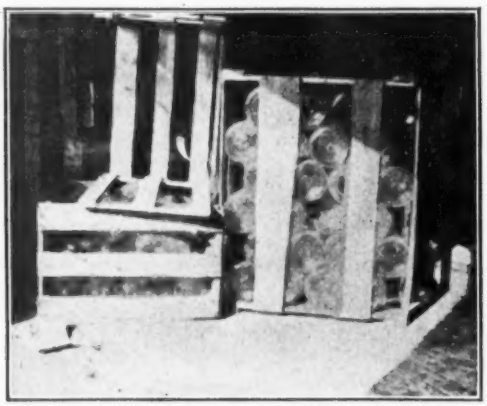


FIG. 9.—Glass bottles shipped from St. Louis, Mo., to Sulphur, Okla.

container may be the only protection against rupture of an inside package and loss of contents. This suggests a broad division of all freight into two classes; one class requiring protection against outside pressure, and the other not requiring such protection.

For the class requiring protection, shipping containers made under standard specifications should be used. Instead of standard specifications we now have unlimited competition in the reduction of cost. The average box maker knows approximately the thickness of lumber that he should use in a given box, but he will cease to be an average manufacturer if he refuses to reduce this thickness to any degree necessary to secure or keep

a customer. The average shipper may know that a fiberboard box does not possess the required strength to protect his material against pressure, but he is liable to take the chance as long as he can collect his freight claims. The shipper who realizes and meets his obligation to use efficient containers feels constrained to follow the example of a less scrupulous rival in reducing the cost of his shipping department.

Many shippers use inefficient containers because they do not know how to specify the characteristics that will insure efficiency. They order barrels or boxes and leave the details to the manufacturers of the packages among whom it is always possible to find some who are willing to sacrifice a lasting reputation for quality to a temporary profit. On the other hand, many of these manufacturers make inferior packages because they do not appreciate the service demanded of their product and because no standard specification has been worked out for their guidance.

Until a few years ago metal cylinders to contain compressed gases, for example, were made in large quantities without adequate specifications. The only requirement was a pressure test. Many lap-welded, unannealed cylinders were placed in service and some have exploded from comparatively slight shocks while the gaseous pressure was less than 30 per cent of the test pressure to which, presumably, the cylinders had been subjected. These explosions have caused loss of life, and the failure to develop and use suitable standard specifications for the manufacture and test of these cylinders before placing them in service is a source of keen regret now to the makers of them, as well as to their present owners.

When the fiberboard box was introduced some years ago as a proposed substitute for the wooden box as a shipping container, the railroads noted its failure in many cases to protect its contents and additional freight charges were assessed as "penalties" against the substitute package. The manufacturers were wise enough to prepare what they considered standard specifications for fiberboard boxes and offered to bring their product up to this standard if the railroads would remove the penalty freight charges. The offer was accepted although it is not known that any attempt was made to verify the sufficiency

of the proposed standard. The acceptance shows the appreciation by railway officials of the value of establishing standards for shipping containers, but in this case it resulted in a material and a double loss to the railroads. The gross weight of freight was reduced and the total of loss and damage claims must have been increased by many attempts to use the substitute package in fields to which it is not adapted. The wooden-box makers did not appreciate the importance of their new competitor and really encouraged its growth by their failure to follow its standardizing example. Many of them fear at the present time that a standard for wooden boxes would, by increasing the average cost, give an increased leverage to the promoters of the substitute package. This fear is not believed to be well founded. If a standard for a stronger package is established it will be used to keep the weaker one from adoption for the shipment of freight that needs protection against pressure.

Even if we could overcome all other impediments to the preparation of standard specifications for all kinds of containers, boxes, barrels, etc., there would still remain the pronounced difficulty of doing so. The thickness of lumber in a box, for example, would have to depend on the kind of lumber, the size of the box, and the weight of the contents. A standard only approximately correct would be better, however, than none; and a serious attempt by one or more experts in each package-manufacturing industry would soon furnish at least an approximately correct standard for the product of that industry.

In Appendix II to this paper will be found samples of specifications approved by the Interstate Commerce Commission. The general plan followed by the writer in preparing these specifications has been to ascertain the best, reasonably secure package voluntarily used previously by shippers for the material in question, and to make this the standard for all. The approval of some body possessing unquestioned authority over both the railroads and the shippers is essential to the successful enforcement of any such standard. Up to this time the Interstate Commerce Commission has exercised its authority only over the containers for explosives and other dangerous articles as defined in its regulations for their safe transportation. It could

exercise the same authority over shipping containers for all kinds of freight, and an expression of opinion of this Society favorable to this action would have a strong and useful influence. The following resolution is, therefore, proposed:

"*Resolved*, That the American Society for Testing Materials, on account of its desire to cooperate and assist in any action that promises to conserve our national resources, respectfully urges upon the Interstate Commerce Commission the advisability of extending, to all classes of freight moving in interstate commerce, the protection against damage and loss through insecure shipping containers that the Commission is now endeavoring to extend to explosives and other dangerous articles; and this Society offers the services of a committee, whose appointment for this purpose is hereby authorized, to assist, so far as the time and experience of its members may permit, in formulating and perfecting standard specifications for shipping containers."

APPENDIX I.

CAUTION TO CONDUCTORS, ENGINEMEN, YARDMEN AND FREIGHT TRAINMEN.

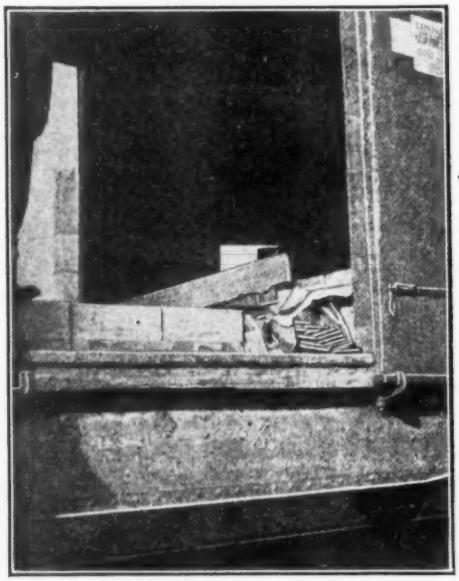


ILLUSTRATION NO. 1.

The above photograph shows a "near accident" to a car containing over 23,000 lb. of high explosives. If an explosion had occurred we should not have known the cause. We now know that the car had been handled very roughly, but the records did not show it. Possibly the train crew responsible did not consider their handling rough, inasmuch as the outside of the car did not show any injury; but 14 boxes of dynamite inside the car were ruptured and loose cartridges were scattered over the floor. Four or five of these cartridges were caught between the door sill and the door and crushed when the door was opened by an inspector of the Bureau of Explosives, who had no reason to suspect the dangerous condition inside of the car. The location of the car at the time was such that an explosion of its contents would have resulted in great loss of life and property.

You will see plainly that the train crew that broke up these boxes set a trap that came near being fatal to a large number of people. They did not intend to set the trap, but this did not lessen the danger. Through ignorance or carelessness they did just what would have been done by a cowardly criminal anxious to assassinate his brother employees.

Remember that modern freight cars can stand without apparent injury shocks that the packages in the cars cannot stand. Read and obey the condensed rules on the Explosive Placard. They are a part of the Federal law and the severe penalties of fine and imprisonment for violations of them apply to you individually and not solely to your company. The same law requires the company to see that you have an opportunity to learn what the law requires of you. You have been furnished with a copy of the regulations; you have been invited to attend the lectures by the Bureau of Explosives and now you have read this bulletin.

If you handle, or help to handle, these explosive cars roughly, or fail to do all you can to keep others from handling them roughly, you will violate the law in letter or in spirit and without any possible justification or excuse.



ILLUSTRATION NO. 2.

The above photograph shows the result of a shock to a wagon load—2800 lb.—of dynamite. This accident happened several years ago.

APPENDIX II.

Twenty-one sets of specifications have been prepared by the Bureau of Explosives for the shipping containers of explosives and other dangerous articles. Those mentioned from Nos. 1 to 6, inclusive, were approved and made effective March 31, 1912. A revision of these and fifteen additional sets, as shown in the list below, will be presented for approval of the Commission in the near future. Following the list will be found three samples of these specifications. Copies of the others can be obtained by application to "Bureau of Explosives, 30 Vesey Street, New York City."

TITLES OF SHIPPING CONTAINER SPECIFICATIONS.

No. 1.....For Glass Carboys and Outside Containers of same when used for the shipment of Inflammable or Corrosive Liquids.

No. 2.....Metal Cans and Boxes for Inflammable Liquids.

No. 3.....Cylinders for the shipment of Carbonic Acid Gas, Nitrous Oxid Gas, Blaugas, and any liquefied gas whose charging pressure at 70° F. exceeds 300 lb. per sq. in.

No. 3A.....Steel Cylinders for the shipment of non-liquefied gases whose charging pressures at 70° F. exceeds 300 lb. per sq. in. and do not exceed 1400 lb. per sq. in.

No. 3B.....Steel Cylinders for the shipment of non-liquefied gases whose charging pressures at 70° F. exceed 1400 lb. per sq. in. and do not exceed 1800 lb. per sq. in.

No. 3C.....Steel Cylinders for the shipment of non-liquefied gases whose charging pressures at 70° F. exceed 1800 lb. per sq. in. and do not exceed 2150 lb. per sq. in.

No. 3D.....Steel Cylinders for the shipment of non-liquefied gases whose charging pressures at 70° F. exceed 2150 lb. per sq. in. and do not exceed 2500 lb. per sq. in.

No. 4.....Cylinders for the shipment of Anhydrous Ammonia.

No. 5.....Iron or Steel Barrels or Drums for Inflammable Liquids or Mixed (Nitrating) Acids.

No. 6.....Boxes for "Strike Anywhere" (Friction) Matches.

No. 7.....Cylinders for the shipment of any gas, not liquefied, and not in solution, whose charging pressure does not exceed 300 lb. per sq. in. at 70° F.

No. 8.....Cylinders for the shipment of Acetylene Gas.

No. 9.....Wooden barrels, half barrels and kegs used for the shipment of inflammable liquids in bulk, whose flash point is less than

20° F., and of those acids which are allowed to be shipped in bulk in wooden barrels.

No. 10.....Wooden barrels, half barrels and kegs used for the shipment of inflammable liquids in bulk whose flash point is not lower than 20° F.

No. 11.....For wooden barrels, half barrels and kegs used for the shipment of inflammable solids or oxidizing materials in bulk or in inside containers or for the shipment of inflammable liquids or corrosive liquids when the same are packed in proper inside containers as authorized by the I. C. C. Regulations.

No. 12.....Boxes to be used as outside containers for Shipping Special Fireworks, or Common Fireworks when in the same box with Special Fireworks.

No. 12A....Boxes to be used as outside containers for shipping Common Fireworks.

No. 13.....Metal kegs for use as outside containers for the shipment of Low Explosives, Black Powder or Smokeless Powder for Small Arms.

No. 14.....Boxes for use as outside containers of High Explosives.

No. 15.....Boxes for use as shipping containers of Blasting Caps.

No. 16.....Boxes for use as outside Containers of Explosives in tight inside Containers, except in cases otherwise specifically provided for.

No. 17.....Boxes for use as outside containers of Wet Nitrocellulose—20 per cent water; Wet Picric Acid—20 per cent water; Wet Trinitrotoluol—20 per cent water; Wet Nitrostarch—20 per cent water, and similar substances.

No. 18.....For metal cans and boxes purchased hereafter and used for the shipment of metallic sodium or potassium, of calcium phosphide, or of white or yellow phosphorus.

No. 20.....For metal barrels and drums purchased hereafter to be used as outside containers of Inflammable Solids and Oxidizing Materials in bulk.

No. 21.....Fiber drums, or barrels to be used for the shipment of Inflammable Solids or Oxidizing Materials in bulk, when such a container is authorized.

SHIPPING CONTAINER SPECIFICATION No. 2.

(See Par. 1822 (*a*), p. 23, and Par. 36, p. 35.)

METAL CANS AND BOXES FOR INFLAMMABLE LIQUIDS.

Revised..... Effective.....

CANS.

1. Cans exceeding 1-gallon and not exceeding 10-gallons capacity must be made of metal not lighter than 30 gage United States standard.

2. Cans not exceeding 1-gallon capacity may be made of metal lighter than 30 gage United States standard, but it must be such as will provide proper protection against leakage in transit.

3. Each completed can must be tested by its manufacturer and must not leak air when tested under water with interior air pressure of at least 5 lb. per sq. in.

BOXES.

4. Boxes must be made of good sound white pine, or any wood of equal or superior strength, dry and well seasoned and with no loose knots in any part nor sound knots on any nailing edge.

5. Thickness of lumber in the finished box must not be less than required by this specification.

6. When ends are cleated, at least 40 per cent of the bottoming nails must be driven into the cleats. Boxes may be made without cleats, provided the tops, bottoms and sides are thicker by $\frac{1}{4}$ in., and the ends thicker by $\frac{3}{8}$ in. than the thicknesses prescribed for cleated boxes.

7. All nails driven through sides, tops or bottoms into ends or cleats must be at not greater than $2\frac{1}{2}$ in. centers.

8. All nails driven through tops or bottoms into sides must be at not greater than 8 in. centers.

9. Gage of nail shall in no instance be less than 4-penny for the smaller boxes, 5-penny and 6-penny for the medium boxes, and 7-penny for the single 10-gallon shipment and for the larger boxes for assorted shipments. Screws of equal efficiency may be used in place of nails.

10. The boxes must cover the cans and the cans must fit tightly in the boxes. The filling hole must be securely closed and if not entirely covered by the box cover it must be completely protected by it.

BOX FOR SINGLE CAN OF CAPACITY NOT OVER 2 GALLONS.

11. *Ends.*—Not less than $\frac{5}{8}$ in. thick.

12. *Sides, Tops, and Bottoms.*—Not less than $\frac{5}{16}$ in. thick, securely nailed with 4-penny coated nails where the grain of the wood is crossed and 5-penny coated nails where the grain of the wood is paralleled in the receiving portion of the end; nails must be placed at approximately 2-in. nail centers.

13. If boxes are made with locked corners the ends must not be less than $\frac{3}{8}$ in. and the sides, tops, and bottoms not less than $\frac{5}{16}$ in. thick.

BOX FOR SINGLE CAN OF CAPACITY OVER 2 GALLONS BUT NOT OVER 5 GALLONS.

14. *Ends.*—Grain vertical, of one-piece material not less than $\frac{5}{8}$ in. thick for nailed uncleated box.

15. *Paneled Ends* may be used with cleats not less than $\frac{5}{8}$ by $1\frac{1}{4}$ in. tenoned; filling not less than $\frac{1}{4}$ in. thick, securely fastened to cleats with clinched nails.

16. *Single-cleated Ends.*—Grain vertical, cleats not less than $\frac{5}{8}$ by $2\frac{1}{2}$ in. Ends proper of two pieces not less than $\frac{5}{8}$ in. thick, cleats securely fastened with clinched nails.

17. *Sides.*—Not less than $\frac{3}{8}$ in. thick, no more than three pieces unless tongued and grooved.

18. Sides must be nailed with not less than six 5-penny coated nails in each nailing surface, and if the box is deeper than 15 in., the number of nails used must be increased so that nailing centers are approximately 2 in. apart.

19. *Tops and Bottoms.*—Not less than $\frac{3}{8}$ in. thick; no more than two pieces, unless tongued and grooved.

Must be nailed to ends with not less than five nails in each nailing surface, and where the receiving portion of the end is with the grain, 6-penny coated nails must be used. If the receiving portion is across the grain of the wood, 5-penny coated nails are acceptable.

20. If boxes are made with locked corners the ends must not be less than $\frac{9}{16}$ in. and the sides, tops, and bottoms not less than $\frac{5}{16}$ in. thick.

BOX FOR SINGLE CAN OF CAPACITY OVER 5 GALLONS BUT NOT OVER 10 GALLONS.

21. *Ends.*—Must be cleated with at least two cleats whether of one or two piece material and not less than $\frac{5}{8}$ in. thick. Cleats not less than $\frac{5}{8}$ by $2\frac{1}{2}$ in., securely fastened with clinched nails.

22. *Sides.*—Not less than $\frac{1}{2}$ in. thick. No more than four pieces unless tongued and grooved, securely nailed with 6-penny coated nails at approximately 2-in. nail centers.

23. *Bottoms.*—Not less than $\frac{1}{2}$ in. thick. No more than two pieces unless tongued and grooved, securely nailed with 6-penny coated nails at approximately 2-in. nail centers; 50 per cent of nails must be driven into cleats.

24. *Tops.*—Not less than $\frac{3}{8}$ in. thick. No more than two pieces unless tongued and grooved, securely nailed with 5-penny coated nails, at approximately 2-in. nail centers.

25. If boxes are made with locked corners the ends must not be less than $\frac{3}{4}$ in., and the sides, tops, and bottoms not less than $\frac{1}{2}$ in. thick, unless made with $\frac{5}{8}$-in. lumber throughout.

BOX FOR MORE THAN ONE CAN. COMBINED CAPACITY OF ALL CANS IN BOX NOT OVER 2 GALLONS.

26. *Ends.*—Not less than $\frac{5}{8}$ in. thick.

27. *Sides, Tops, and Bottoms.*—Not less than $\frac{5}{16}$ in. thick, securely nailed with 4-penny coated nails where the grain of the wood is crossed and 5-penny coated nails where the grain of the wood is paralleled in the receiving portion of the end; nails must be placed at approximately 2-in. nail centers.

28. If boxes are made with locked corners the ends must not be less than $\frac{3}{8}$ in. and the sides, tops, and bottoms not less than $\frac{5}{16}$ in. thick.

BOX FOR MORE THAN ONE CAN. COMBINED CAPACITY OF ALL CANS IN BOX OVER 2 GALLONS BUT NOT OVER 6 GALLONS.

29. *Ends.*—One piece, not less than $\frac{3}{4}$ in. thick. If more than one piece not less than $\frac{5}{8}$ in. thick, single cleated.

Cleats not less than $\frac{3}{8}$ by 2 in., securely fastened with clinched nails.

30. *Sides, Tops, and Bottoms.*—Not less than $\frac{3}{8}$ in. thick, nailed at approximately 2-in. nail centers with 5-penny coated nails where the grain of the wood is crossed and 6-penny coated nails where the grain of the wood is paralleled in the receiving portion.

31. If boxes are made with locked corners, the ends must not be less than $\frac{9}{16}$ in. and the sides, tops, and bottoms not less than $\frac{3}{8}$ in. thick.

BOX FOR MORE THAN ONE CAN. COMBINED CAPACITY OF ALL CANS IN BOX OVER 6 GALLONS BUT NOT OVER 12 GALLONS.

(Provided that 2 cans with a capacity not exceeding 5 gallons each may be shipped in a box made according to Paragraphs 38 and 39.)

32. *Ends.*—Not less than $\frac{3}{4}$ in. thick, cleated with $\frac{5}{8}$ by $1\frac{7}{8}$ in. cleats, securely fastened with clinched nails.

33. *Sides, Tops, and Bottoms.*—Not less than $\frac{3}{8}$ in. thick, nailed at approximately 2-in. centers, with 6-penny coated nails throughout.

34. If boxes are made with locked corners the ends must not be less than $\frac{3}{4}$ in. and the sides, tops, and bottoms not less than $\frac{1}{2}$ in. thick.

BOX FOR MORE THAN ONE CAN. COMBINED CAPACITY OF ALL CANS IN BOX OVER 12 GALLONS BUT NOT OVER 20 GALLONS.

35. Must be not less than $\frac{3}{4}$-in. lumber throughout, with single cleated ends, using cleats $\frac{3}{4}$ by 3 in. that are securely fastened with clinched nails.

36. *Sides, Tops, and Bottoms.*—Must be nailed at approximately 2-in. nail centers with nails not smaller than 7-penny coated.

37. If boxes are made with locked corners the lumber must be $\frac{3}{4}$ in. throughout.

BOX FOR TWO CANS WITH A CAPACITY OF NOT OVER 5 GALLONS EACH.

38. *Ends.*—Grain vertical, of one-piece material not less than $\frac{3}{4}$ in. thick.

Other styles of ends like single 5-gallon box.

Balance of specifications, including nailing, same as single 5-gallon box except that at least two nails must be driven through the bottom into the center of the sides.

39. If boxes are made with lock corners the ends must not be less than $\frac{5}{8}$ in. and the sides, tops, and bottoms not less than $\frac{3}{8}$ in. thick.

MARKING OF BOXES.

40. Each box must be plainly marked with the words "COMPLIES WITH I. C. C. SPEC'N No. 2."

WIRE-BOUND BOXES.

41. Wire-bound packing boxes for cans of any capacity containing inflammable liquids, must be made of sound lumber of not less than the following thicknesses and in accordance with the following specifications:

42. Good sound white pine or any wood equal or superior in strength is acceptable. All lumber used must be dry and well seasoned; no loose knots in any part.

Minimum thicknesses of lumber specified refer to the actual thicknesses in the finished boxes.

43. There must be four cleats at each end of each box not less than $\frac{11}{16}$ by $1\frac{1}{8}$ in.

The binding wire at each end must be firmly stapled to each cleat by staples not less than No. 16 gage and having legs not less than $1\frac{1}{8}$ in. long, extending over the wire, through each board, and into the cleats. The other wire or wires must be firmly stapled to each board by staples not less than No. 18 gage, extending over the wire, through each board, and firmly clinched on the inside. Staples shall not be more than 3 in. apart. Each wire shall be continuous with the ends tightly twisted at one side.

The distance between the encircling wires on each box shall not exceed 8 in. in any instance.

The ends shall be firmly fastened to the inside of cleats with staples not less than No. 16 gage, whose legs are not less than $\frac{13}{16}$ in. long, placed approximately 3 in. apart, or with nails not less than $\frac{7}{8}$ in. long.

WIRE-BOUND BOX FOR A SINGLE CAN OF ANY SIZE.

4. Binding wires shall not be less than No. 16 gage. Lumber shall not be less than $\frac{3}{16}$ in. thick.

WIRE-BOUND BOX FOR MORE THAN ONE CAN. COMBINED CAPACITY OF ALL CANS IN BOX NOT OVER 6 GALLONS.

44. Binding wires shall not be less than No. 16 gage. Lumber shall not be less than $\frac{3}{16}$ in. thick.

WIRE-BOUND BOX FOR MORE THAN ONE CAN. COMBINED CAPACITY OF ALL CANS IN BOX OVER 6 GALLONS BUT NOT OVER 12 GALLONS.

45. Binding wires shall not be less than No. 15 gage.
Lumber shall not be less than $\frac{3}{16}$ in. thick.

WIRE-BOUND BOX FOR MORE THAN ONE CAN. COMBINED CAPACITY OF ALL CANS IN BOX OVER 12 GALLONS BUT NOT OVER 20 GALLONS.

46. Binding wires shall not be less than No. 14 gage.

Lumber shall not be less than $\frac{1}{4}$ in. thick. An additional cleat or batten $\frac{11}{16}$ by $1\frac{1}{8}$ in. shall be placed vertically at the center of each end where the end exceeds 10 in. in width. This additional cleat or batten shall fit in between the horizontal cleats and be held by nails through these cleats into their ends.

MARKING OF BOXES.

47. Each box must be plainly marked with the words "COMPLIES WITH I. C. C. SPEC'N No. 2."

SHIPPING CONTAINER SPECIFICATION No. 3.

(See Par. 1822 (*a*).)

CYLINDERS FOR THE SHIPMENT OF CARBONIC ACID GAS, NITROUS OXID GAS, BLAUGAS, AND ANY LIQUEFIED GAS WHOSE CHARGING PRESSURE AT 70° F. EXCEEDS 300 LB. PER SQ. IN.

Revised..... Effective.....

1. Cylinders must be made seamless, of steel of uniform quality, to comply in the present state of the art with the following specifications:

CHEMICAL ANALYSIS.

2. Carbon must not exceed..... 0.55 per cent.
Phosphorus must not exceed..... 0.04 "
Sulphur must not exceed..... 0.05 "

ANNEALING.

3. All cylinders after finishing must be uniformly and properly annealed. Dirt and scale must be removed before painting.

FLATTENING TEST.

4. From each lot of 200 or less a representative finished cylinder, after annealing, must be selected at random and must withstand without cracking, flattening between rounded knife edges to a thickness of six times the thickness of the wall of the cylinder, this measurement to be made between the outside surfaces of the walls of the cylinder.

The knife edges must be of wedge shape, converging at an angle of 60 deg., the point being rounded off with a radius of $\frac{1}{2}$ in. If any one cylinder from any lot fails to pass this test, two others from the same lot must be selected, and these must pass it in order to have the lot accepted. If it should appear that failure in the test is due to improper annealing, the manufacturer has the privilege of reannealing the lot and repeating the test.

PHYSICAL TESTS.

5. One out of each lot of 200 or less finished cylinders after annealing must be selected at random and tests made on test specimens cut longitudinally therefrom to determine the elatic limit, the tensile strength, and the elongation of the material. These test specimens should, when practicable, be taken from the same cylinders which are used for the flattening test.

The elongation must be not less than 10 per cent on an 8-in. test specimen.

The elastic limit must not be more than 67 per cent of the tensile strength.

HYDROSTATIC TEST.

6. Each finished and annealed cylinder must be subjected to a hydrostatic test of not less than 3000 lb. per sq. in. in a water jacket, or other apparatus of suitable form, to furnish reliable data. The permanent volumetric expansion must not exceed 5 per cent of the whole volumetric expansion at this pressure. This test must be made without subjecting the cylinder to any previous hydrostatic pressure; provided, however, that a preliminary pressure of 2800 lb. per sq. in. may be applied once only, previous to the official test, for the purpose of rounding out the cylinder.

If, without subjecting the cylinder to any rounding-out pressure, the permanent volumetric expansion of 3000 lb. pressure exceeds 5 per cent but does not exceed 10 per cent of the total volumetric expansion, the manufacturer has the privilege of retesting the cylinder at a pressure of 3200 lb. per sq. in. This retest must be made without any intermediate application of pressure and the permanent volumetric expansion must not exceed 5 per cent of the total volumetric expansion.

7. In the hydrostatic test the water gage indicating the expansion must be of such diameter that the total expansion will cause the water to rise at least 18 in. in the gage; the pressure must be applied for not less than 20 seconds and as much longer as may be necessary to insure complete expansion of the cylinder. The expansion must be recorded in cubic centimeters.

MARKING.

8. Each cylinder must be plainly and permanently marked on the shoulder with a serial number and with the initials of the owner or owning company.

9. Each cylinder must also be plainly and permanently marked with the words "COMPLIES WITH I. C. C. SPEC'N No. 3," or, if desired by the purchaser, a symbol consisting of a circle quartered diagonally as follows:



The diameter of this circle must be at least $\frac{3}{4}$ in. and the letters and figures must be at least $\frac{7}{32}$ in. high.

This symbol shall be understood to certify that the cylinder complies with all the requirements of this specification.

10. The date of the hydrostatic test must also be stamped on the cylinder (for example 4-09 for April, 1909) in such manner that the dates of subsequent quinquennial tests required by Paragraph 1861 (*e*) may be easily added thereto.

GENERAL CONSTRUCTION.

11. All plates or tubes from which cylinders are made must be free from seams, cracks, laminations, or any defects which may prove injurious to the finished cylinder.

12. The manufacture of the cylinders must be completed with the best appliances and according to the best modern methods. All finished cylinders must show reasonably smooth and uniform surface finish, inspection of inside surface to be made before necking down; the threading of valve seat and of flange must be even and without checks and the cylinders must show no defects of workmanship or material likely to result in any appreciable weakness of the finished cylinder. A close inspection of each completed cylinder must be made before acceptance to discover any defect.

INSPECTION.

13. The purchaser must provide for inspection of all material and all tests by a competent and disinterested inspector.

14. The inspector must keep complete records of the various melts from which the steel is taken for the manufacture of the cylinders. Certified chemical analyses of these melts must be supplied to him by the manufacturer, or, if desired by the purchaser, he must procure samples from each melt from which other chemical analyses may be made. The heat number must be stamped on the plates and billets at the steel mill and the inspector must also stamp his initials or personal sign on each plate or billet accepted by him and no plate or billet must be used for the manufacture of cylinders unless so marked.

Provided: that, when cylinders are to be made from drawn seamless tubing under conditions such that the various heats of steel cannot be properly traced through to the finished cylinders, a certificate from the manufacturer of the tubing (see Report, Par. 19, for form of certificate) together with check analyses of samples taken from one out of each lot of 200 or less finished cylinders, shall be accepted.

15. The inspector shall verify the thickness of walls of each cylinder before necking down and shall witness the hydrostatic and flattening tests of all cylinders.

16. The inspector shall stamp his initials or his personal sign immediately beneath the serial number on each cylinder which he passes as accepted and shall make a certified report (see Par. 19) to the maker, to the purchaser and to the Chief Inspector, Bureau of Explosives, 30 Vesey Street, New York City, showing the serial numbers of all cylinders which are accepted together with a copy of all data relating to the material and the tests.

EXEMPTIONS FOR CYLINDERS OF SMALL DIMENSIONS.

17. Cylinders and other containers which have an outside diameter of less than 2 in. and a length of less than 2 ft. shall be accepted without complying with the requirements of Paragraphs 5, 6, 7, 8, 9, 10, 13, 14, 15, 16 and 19 of this specification under the following conditions:

(*a*) All such containers of whatever size or shape shall be considered and known as cylinders.

(*b*) The design and construction must be approved by the Chief Inspector, Bureau of Explosives, 30 Vesey Street, New York City.

(*c*) From each lot of 500 or less a representative finished cylinder must be selected at random and subjected to hydrostatic pressure until it bursts. The bursting pressure must be noted in the report required by paragraph 17 (*f*), and must not be less than 6000 lb. per sq. in.

(*d*) Each cylinder must be subjected to a hydrostatic pressure of not less than 3000 lb. per sq. in. without showing any apparent defect.

(*e*) Each cylinder must be marked with a rectangle as follows:

X—XX—I. C. C.—3.

the stars to be replaced by a date showing month and year of manufacture (for example, 5-13 to indicate May, 1913). If the cylinders are numbered this marking must be immediately below the number.

This marking shall be held to certify that all the requirements of this specification have been complied with except as exempted above.

(*f*) A report, giving complete data and certifying that all requirements of this specification have been complied with, must be made to the Chief Inspector, Bureau of Explosives, 30 Vesey Street, New York City. This report may be rendered by the manufacturer instead of by an outside inspector.

ADDITIONAL REQUIREMENTS.

18. The purchasers of cylinders may impose additional requirements not inconsistent with these specifications.

REPORTS.

19. The report required by paragraph 16 must be submitted in the following form:

(Place).....

(Date).....

REPORT OF INSPECTION OF.....Cylinders
numbered from.....to .....inclusive.
Manufactured by the.....Company.
Inspected for the.....Company.

Inspection was made on.....cylinders, manufactured by the .....Company for the.....Company, in accordance with the requirements of Shipping Container Specification No. ..... of the Interstate Commerce Commission Regulations.

The steel from which these cylinders were manufactured was made by the.....Company. Chemical analyses were made from

samples representing each melt of steel, as will be observed from the report of chemical test hereto attached.[2]

The [1] (plates)—(tubes) from which these cylinders were manufactured were inspected by....., and those which were accepted were found free from seams, cracks, laminations or any defects which might prove injurious to the strength of the cylinder.

Each and every cylinder before [1](necking down)—(closing) was inspected inside and outside for surface defects, and the thickness of walls were measured at points not more than 8 in. from the open end of the cylinder with a pair of calipers and the minimum thickness of wall noted was.....

Each and every cylinder was [1] (necked down)—(closed) and was uniformly and properly annealed and then the cylinders were again inspected in order to discover any defects which might have been caused by this process.

One out of each lot of 200 or less finished cylinders was selected by the Inspector and subjected in his presence to a flattening test as required by the Interstate Commerce Commission Specifications. All of the cylinders passed this test satisfactorily.

Two longitudinal test pieces were cut from each crushed cylinder and pulled.

The record of the physical and flattening tests is attached hereto.

Each and every cylinder was subjected to the proper hydrostatic test in the presence of the Inspector. A rounding-out pressure of not more than 2800 lb. per sq. in. [1] (was)—(was not) made. The record of the hydrostatic tests is attached hereto.

Each and every cylinder was stamped on the.....with the initials .....of the purchasing company, and with the date of test.

Each and every cylinder was stamped with the initials.....of the Inspector immediately beneath the serial number of the cylinder.

Each and every cylinder was plainly marked on the shoulder with the wording specified in Paragraph 9 of this specification. (State which form was used.)

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[1] Draw a line through word not required.

[2] If the cylinders are made from drawn seamless tubing under such conditions that it is impossible to trace the various heats of steel through to the finished cylinder (see Par. 14), this paragraph should be replaced by the following:

The tubing from which these cylinders were manufactured was made by the..... .....Company under orders No....., and their certificate stating that it complies with the requirements of this specification is attached hereto. Check analyses were made from samples representing each lot of 200 or less cylinders, as will be observed from the report of chemical tests attached hereto.

Also, the report must be accompanied by a certificate from the manufacturer of the tubing as follows:

(Place).....

(Date).....

This is to certify that the tubing furnished to the.....Company on orders No.....does not contain more than 0.55 per cent of carbon, nor more than 0.04 per cent of phosphorus, nor more than 0.05 per cent of sulphur.

.....

(Signature of Mfr. of tubing.)

This form to be used only when cylinders are made from drawn seamless tubing. (See Par. 14.)

I hereby certify that all of these cylinders proved satisfactory in every way, and comply with the requirements of the Interstate Commerce Commission Specification No.....and with Paragraph 1822a of the Interstate Commerce Commission Regulations.

.....

Inspector.

Note: If any defects are found in completed cylinders, state kind and cause, and that said cylinders were rejected.

(Place).....

(Date).....

RECORD OF CHEMICAL ANALYSIS OF MELTS FROM WHICH STEEL WAS TAKEN FOR THE MANUFACTURE OF.....CYLINDERS BY THE.....COMPANY FOR THE.....COMPANY.

Test No.	Melt No.	Test Piece Represents	Chemical Analysis						Accepted or Rejected.	Remarks.
			C	P	S					

(Signed).....

(Place).....

(Date).....

RECORD OF PHYSICAL AND FLATTENING TESTS MADE ON.....CYLINDERS, MANUFACTURED BY THE.....COMPANY FOR THE.....COMPANY. SERIAL NUMBERS OF CYLINDERS ARE.....TO....., INCLUSIVE.

Test No.	Numbers of Cylinders Represented by Test Piece.	Elastic Limit, lb. per sq. in.	Tensile Strength, lb. per sq. in.	Elongation, per cent in 8 in.	Reduction of Area, per cent.	Flattening Test.	Accepted or Rejected.

(Signed).....

(Place).....

(Date).....

RECORD OF HYDROSTATIC TESTS MADE ON.....CYLINDERS,.....O. D. X.....LONG, MANUFACTURED BY THE.....COMPANY FOR THE.....COMPANY.

Number of Cylinder.	Test Pressure.	Weight.	Thickness of Walls.	Total Expansion. (cc.)	Permanent Expansion. (cc.)	Per Cent.	Accepted or Rejected.

(Signed).....

NOTE.—If any cylinders are retested at the increased pressure as allowed, the total expansion, permanent expansion and per cent must be recorded for both tests.

SHIPPING CONTAINER SPECIFICATION No. 5.

(See Par. 1822 (*a*), p. 23, and Par. 38, p. 35.)

IRON OR STEEL BARRELS OR DRUMS FOR INFLAMMABLE LIQUIDS OR MIXED (NITRATING) ACIDS

Revised..... Effective.....

1. The provisions of this specification apply to all containers specified herein that are purchased after December 31, 1911.

2. Each such container purchased subsequently to December 31, 1911, shall have plainly stamped thereon the date of manufacture thereof.

3. An iron or steel barrel or drum with a capacity of over 55 gallons but not over 110 gallons must be constructed of metal the minimum thickness of which in any part of the completed barrel or drum must not be less than that of full No. 14 gage, United States standard.

The weight of a barrel or drum with a capacity of 100 to 110 gallons must be not less than 130 lb. in the black exclusive of the rolling hoops.

4. An iron or steel barrel or drum with a capacity of over 30 gallons but not over 55 gallons must be constructed of metal the minimum thickness of which in any part of the completed barrel or drum must not be less than that of full No. 16 gage, United States standard.

The weight of a barrel or drum with a capacity of 50 to 55 gallons must be not less than 70 lb. in the black exclusive of the rolling hoops.

5. An iron or steel barrel or drum with a capacity of over 10 gallons but not over 30 gallons must have a minimum thickness of metal in any part of the barrel or drum of not less than full No. 18 gage, United States standard.

6. An iron or steel barrel or drum with a capacity of not more than 10 gallons must have a minimum thickness of metal in any part of the barrel or drum of not less than full No. 20 gage, United States standard.

7. Each barrel or drum must be tested and must stand without leaking a manufacturer's test under water by interior compressed air at a pressure of not less than 15 lb. per sq. in., sustained for not less than 2 minutes.

8. The type of barrel or drum must be capable of standing without any serious permanent deformation and without leaking a hydrostatic test pressure of not less than 40 lb. per sq. in., sustained for not less than 5 minutes.

9. When filled with water to 98 per cent of its capacity the type of barrel or drum must also be capable of standing without leakage a test drop on its chime from a height of 4 ft. upon a solid concrete foundation.

10. Bungs and other openings must be provided with secure closing devices that will not permit leakage through them. Threaded metal plugs must be close fitting. Gaskets must be made of lead, leather, or other suitable material. Wooden plugs must be covered with a suitable coating and must have a driving fit into a tapered hole.

11. The method of manufacturing the barrel or drum and the materials used must be well adapted to producing a uniform product. Leaks in a new barrel or drum must not be stopped by soldering but must be repaired by the method used in constructing the barrel or drum.

12. Each barrel and drum must be plainly and permanently marked with the words "COMPLIES WITH I. C. C. SPEC'N No. 5."

DISCUSSION.

Mr. Speller. MR. F. N. SPELLER.—So many interests are involved in the handling of freight that the selection of safe and economical packages should be left to somebody whose interest in the matter is neutral. It is by no means a simple problem to balance these antagonistic interests and to draw up specifications for shipping containers which will be best for all concerned.

The preparation and results accomplished by the Shipping Container Specification I. C. C. No. 3, covering cylinders for the shipment of gases under pressure, illustrate very well the point of Colonel Dunn's paper.

Before the adoption of this specification, such cylinders were manufactured under specifications of the purchaser, who is usually the shipper. His inclination to purchase the cheapest and lightest-weight cylinder was only restrained by his own limited experience, and such influence as the manufacturer could bring to bear.

The preparation of a specification by the Bureau of Explosives very naturally led to far more extensive research and experiment than was deemed necessary under previous conditions, both as to the material of which the cylinders were made, and the physical properties of the contents at various temperatures and pressures. This work has received the hearty support of the leading interests concerned. The result has been the adoption of a specification based on the best information obtainable, and an improvement in conditions which should greatly reduce the hazard to both life and property.

An enormous amount of work has been done on this specification and at great expense, a general description of which would involve a lengthy paper. To how great an extent similar results can be accomplished by drafting specifications for other materials subject to injury or likely to cause damage in transportation, it is impossible to say.

It may be of interest here to say a word as to the development of the cylinder which we are making in this country

to-day for carrying gas under pressure. These cylinders were first made in America in 1891, and for two years afterwards, of lap-welded wrought iron, tested at first to 2500 lb., and then as required by the purchaser to 3700 lb. internal pressure. Lap-welded Bessemer steel was substituted in 1893 and continued to be made until 1908. During this period the seamless cylinder was developed, and about 80,000 manufactured. After 1908 no lap-welded cylinders were made. Considering the high and variable stress to which these cylinders are subjected, and the rough handling in transportation, to which Colonel Dunn's paper makes reference, it is little wonder that once in a while one of these old cylinders explodes under shock. The high test-pressure applied must have frequently strained the metal considerably beyond its elastic limit. The pressure is now reduced to 3000 lb., which is slightly below the elastic limit of the modern cylinder. We now know that annealing to refine the grain will greatly increase the resistance of these lap-welded cylinders to shock, but to be permanently effective this annealing should be repeated every four or five years. **Mr. Speller.**

THE PRESIDENT.—Perhaps the best way to bring this paper before you for proper discussion would be the consideration of the resolution at the close of Colonel Dunn's paper, namely: **The President**

> "*Resolved*, That the American Society for Testing Materials, on account of its desire to cooperate and assist in any action that promises to conserve our national resources, respectfully urges upon the Interstate Commerce Commission the advisability of extending, to all classes of freight moving in interstate commerce, the protection against damage and loss through insecure shipping containers that the Commission is now endeavoring to extend to explosives and other dangerous articles; and this Society offers the services of a committee, whose appointment for this purpose is hereby authorized, to assist, so far as the time and experience of its members may permit, in formulating and perfecting standard specifications for shipping containers."

In proper course this resolution should be referred to the Executive Committee, for it involves the apppointment of a committeee, which lies entirely in their province. It would be perfectly proper, however, for this resolution to be amended or altered in its phraseology to make the expression one of recommendation to the Executive Committee that they shall take action upon it. Has any one any remarks to offer?

Mr. Stone. MR. G. C. STONE.—I think the shippers would welcome action of the kind proposed in this resolution. The difficulty of getting proper material is increasing all the time, and with these specifications in force it would help us very much in that respect. Another thing I should like to see considered is the proper loading and bracing of the cars. Colonel Dunn's pictures have shown the importance of this and what he says is undoubtedly true. With the old light cars you could load material in pretty much any way and the containers would stand what the cars could stand; but now, with the stronger cars, it is necessary to brace the material and load it properly. We are shipping largely in barrels and find that the bracing is quite as important as the container, and that should be considered by the committee.

The Secretary. THE SECRETARY.—I move that the first part of this resolution, ending with the words "dangerous articles," be adopted as expressive of the sense of this meeting; and that the remainder of the resolution be referred with power to the Executive Committee with a favorable recommendation. [Motion seconded.]

Mr. Becher. MR. EUGEN BECHER.—The Blaugas Company of America, as well as all its subsidiary companies operating in the various parts of the United States, is subject to the rules and specifications which the Interstate Commerce Commission has issued regarding the shipment of compressed gases. When Colonel Dunn, as head of the Bureau for the Safe Transportation of Explosives and other Dangerous Articles, started to issue rules regarding the shipment of compressed gases, we had the impression that most rules and specifications were absolutely justified, and would prove beneficial to the industry. There were, however, some details in the specifications which we thought might prove a burden to the industry. However, after having operated under the rules and specifications for several years, we, as well as perhaps every other manufacturer of compressed gases, have realized more and more the benefit which all manufacturers of compressed gases are deriving from these specifications, and now do not feel them to be an encumbrance at all. Colonel Dunn's work has caused the American manufacturers of compressed gases to study the quality of their cylinders more thoroughly than before, and this is perhaps the main reason why

the quality of steel cylinders used to-day is far superior to the quality of the average steel cylinders which were used a number of years ago. Mr. Becher.

Colonel Dunn has always been very anxious to work in harmony with the manufacturers of compressed gases, as well as with the manufacturers of steel cylinders, and certainly deserves great credit for the work that he has done in this respect. We therefore feel confident that if he will succeed in inducing the Interstate Commerce Commission to issue rules and specifications for containers used by other industries, his work will prove very beneficial to those industries.

MR. H. E. STURCKE.—The importance of Colonel Dunn's resolution can properly be demonstrated by a few figures. In 1907, the property lost by explosives in transit amounted to nearly $500,000. In 1912, due to the activity of Colonel Dunn's Bureau, that loss was reduced to $10,200—from $500,000 to $10,200! Naturally, the railroads would like to see the losses in other merchandise reduced in the same proportion. The large shippers, shippers in general, would probably, to start with, find a great deal of fault with any such activities on the part of the Interstate Commerce Commission. When they have gone through the experience that the shippers of "other dangerous articles" have gone through, they will be as grateful to Colonel Dunn, probably, as we are to-day. Five years ago we thought Colonel Dunn was a nuisance; to-day we see in him in more than one respect the best friend that the compressed gas manufacturer has, owing to his recommendations and his specifications. We know to-day a great deal more about our containers, and whereas, in years gone by, we walked through our factories with fear and trembling, we now have a reasonable sense of safety which is really due to Colonel Dunn. Mr. Sturcke.

As far as the actual specifications are concerned, I am not ready to admit that they are the best we ought to have, but they are probably the best we can get at present. I believe that even if the Society should not be ready to take up the general scope of recommendations covering all packages, the appointment of a committee to investigate the cylinder conditions—I refer to containers for compressed gases—would be entirely in order. Some of you gentlemen who have had expe-

Mr. Sturcke. rience with the testing of these cylinders and the various specifications, know that there is still much uncertainty about some points, which ought to be removed. The various methods of testing need to be investigated by people of scientific authority.

Mr. Fairburn. MR. W. A. FAIRBURN.—As representing manufacturers who have had a great deal of experience with Colonel Dunn in his work during the last few years, I wish to state, not only as a representative of the Diamond Match Co., but as a member of the match manufacturers' committee on shipping containers, that I trust this Society will do all it can consistently to support Colonel Dunn, both morally and by real effective cooperation in the splendid work he is doing along the lines of the conservation of property and life. At first we felt that Colonel Dunn was going to hit us all pretty hard, and I guess he has, but by looking at the question in its broadest light, we have to admit that he has encouraged us to do the right thing and the proper thing. I feel to-day that the field has only just been touched; there is so much ahead yet untouched, that the work is really only in its infancy.

I am very glad to know that Colonel Dunn's organization is considering the preparation of specifications for many other commodities, in addition to explosives and inflammables. I think the present specifications should possibly be further strengthened by degrees in regard to the carrying of dangerous articles, but the general, broad proposal of putting suitable and efficient containers on the various commodities that have to be shipped is certainly one which will result in the greatest possible good to the railroads, and ultimately to manufacturers and the public generally. Without taking up your time by going into this matter technically or by telling you what the match manufacturers have done, working in conjunction with Colonel Dunn, I just want to state that I sincerely trust that this Society will cooperate with Colonel Dunn in every possible way, so that he may feel that he has your moral support. I also hope that you may be able to see your way clear to pass the resolution which will show in a definite manner that you endorse the work he has done.

[The motion on the resolution was then put to vote and carried.]

THE PRESIDENT.—I am sure that the Society, as well as the country and all humanity, should feel grateful to Colonel Dunn for his admirable work. **The President.**

MR. J. J. DAUCH (*by letter*).—The subject of Colonel Dunn's important paper stands in close relation to some matters which he has only touched upon, and which seem to the writer to deserve further discussion. Having in contemplation certain reforms in the specification and enforcement of standards for freight containers, Colonel Dunn quite properly confines himself to argument and recommendation under that head. However, we do find him making incidental reference to the tendencies of the shipping public and the conditions of modern transportation—subjects so interrelated with the main question that no proper conclusion can be reached if they are neglected or misunderstood. **Mr. Dauch.**

In the third paragraph of his paper Colonel Dunn makes the following remark: "Common carriers have always had a legal right to specify the packing required for different kinds of freight." The principle thus stated has usually been accepted unchallenged and unqualified and no maker of standard shipping boxes, who has been made even remotely responsible for inferior competitive goods, would assail the carriers' right, moral or "legal," to specify and require suitable freight packages. The existence of such rights, as yet unexercised, I could not doubt. However, it may be well to be reminded that railways are agents and beneficiaries of the public, exercising prerogatives which entail responsibility. To me it seems clear that the "right" of carriers to specify packing has always been limited by their obligation to specify fairly and reasonably, and that reason and fairness never did and never will relieve them of responsibility for their own acts and policies.

Further on, Colonel Dunn cites as new and extra hazards of transportation, the automatic coupler, the gravity switching track and the steel underframe freight car. The air-controlled freight train might well be added to this list. In all academic discussion of packing standards, it seems to have been taken for granted that in the installation of these facilities, the railways have naturally and properly laid the shipper under obligation to provide against the stresses of their operation. The

Mr. Dauch. standard package is assumed to be the one that will successfully resist the strains imposed by the progressive operating economies of the carriers. Projected to its legitimate conclusion, this assumption would warrant the specification of armor-plated freight boxes should the railways adopt less destructible cars or more expeditious switching methods and facilities. Because of railway improvement, the package standard of yesterday is found insufficient to-day; the standard of to-morrow is therefore made to depend upon future transportation methods now beyond the reach of conjecture.

In the carrying of passengers, the railways themselves assume the risks imposed by new and extra hazardous service, even though such service may have been instituted solely for the convenience of the traveling public. Witness the installation of block signal systems along with the launching of swifter trains. The traveler is not required to encase himself in chain mail; he is rather invited to a steel steam-heated car, and every precaution is taken for his adequate protection from injury. Why then in the movement of freight should the rule be reversed and the public required to provide against the hazards of the "hump," the air-brake, and the automatic coupler? Why should not the railroad recognize its responsibility for the consequences of its own economies and set itself the task of minimizing them?

The adequate and effective standardization of shipping boxes to meet the ordinary stress of handling and transportation is a propriety already too long neglected, but any tendency to use it for relief of carriers from liabilities created wholly by themselves should be carefully avoided.

Caution should also be exercised lest the burden laid upon the shipper by standardization be disproportionate to the gravity of the abuses sought to be corrected. In the packing of commodities which endanger other property, and even human life, safety is the one paramount consideration, but in the case of ordinary freight no such risk is involved, and cost of packing rises to the full height of its importance. Every package of freight damaged in transit involves an economic loss, and so does every dollar unnecessarily absorbed in packing expense. Admitting no such actual ratio of breakage, let us suppose that

ninety-nine of every hundred packages now move safely; then any increase in the value of the prescribed container would be for the sole protection of the hundredth package and should not be out of proportion to the decimal of benefit to be derived. Colonel Dunn mentions that our annual national loss by damage to freight in transit is estimated at some thirty million dollars. Of this enormous drain upon our resources a considerable part may be assumed to flow from railway treasuries, while a portion only of this, the carriers' share, is chargeable to insecure packing. Mr. Dauch.

I am not aware of any estimate yet placed upon the added cost of packing contemplated by the railways, but it is impossible to doubt that without recourse and reference to costs, the ablest men, charged with the preparation and enforcement of packing regulations and actuated by the purest motives, with science as their warrant, could lay upon our shipping interests a tax, beside which the abuses corrected and the savings shown would shrink into insignificance.

The fear of such an outcome is not allayed by observation of a quite prevalent attitude of mind toward those who furnish the revenues of the railroads. I quote again from Colonel Dunn's paper: "The average shipper may know that a fiberboard box does not possess the required strength to protect his material against pressure, but he is liable to take the chance as long as he can collect his claims." From somewhat intimate business relations with "the average shipper" throughout a period of years, I am aware of the promptness and insistence of his customers' complaints whenever his shipping boxes do not carry satisfactorily. I also know how invariably he chooses a more expensive package in preference to that loss of trade which would inevitably result from improper packing of his wares. As an "average shipper," I have discovered no temptation in railroad claims, and all my experience has proven to me that shippers will avoid them if they can.

Concerning the acceptance of fiber boxes on a parity with those of wood Colonel Dunn speaks as follows: "It resulted in a material and a double loss to the railroads. The gross weight of freight was reduced and the total of loss and damage claims must have been increased by many attempts to use the

Mr. Dauch. substitute package in fields to which it is not adapted." Those who are advocates of "conservation" will be able to recognize in the first of these twin "losses" a distinct economic saving. As to the other, abundant examples of breakage prevention credited to the fiber box must serve to offset the unsupported opinion we have quoted.

Thorough standardization will come; it must come. Public policy demands it. But it should not be undertaken with any prejudice that may affect its equity, nor without full recognition of the relative obligations of carrier and shipper. It is therefore to be hoped that whoever shall eventually take up this great work may bring to it not only breadth of technical knowledge, but also that judicial poise which shall insure to all a fair division of responsibility, and a just relation of the burden lifted to the tax imposed.

Col. Dunn. COL. B. W. DUNN (*Author's closure by letter*).—The author desires to express his grateful appreciation of the valuable support received from the gentlemen who participated in this discussion.

It probably will be guessed by the reader that any one of the gentlemen commenting on the work already accomplished in standardizing the manufacture and testing of steel cylinders, for use as shipping and storage containers for compressed gases, could write an instructive chapter on this subject.

It is not just to accord the author more than a small part of the credit due for the valuable standardization of shipping containers for explosives and other dangerous articles already accomplished. These specifications represent the result of much labor and the expenditure of a considerable amount of money by public-spirited citizens and by employees of the Bureau of Explosives.

The valuable letter contributed to this discussion by Mr. Dauch contains strong support for the author's contention and recommendation, with a caution against any failure to appreciate that the burdens incident to safer transportation should be distributed equitably between the shipper and the carrier. It was not the intention of the author to advocate any course not in harmony with this caution. This has been the essential feature of the policy of the Bureau of Explosives in framing

Col. Dunn.

regulations and specifications for submission to the Interstate Commerce Commission. To require the packing of several hundred pounds of valuable merchandise in a box made of armor plate would be only a degree more unreasonable than to permit its shipment in a box made of lumber only $\frac{1}{8}$ in. thick.

Neglecting wrecks and the occasional destruction of freight by the carelessness and indifference of railway employees, it cannot be doubted that stern necessity has forced the carriers to increase the sev)rity of the average treatment of freight incident to transportation. This necessity flows from a keen appreciation by the carrier of that responsibility to serve its patrons acceptably, which Mr. Dauch emphasizes. If he will visit the office of a traffic manager of an association of shippers in any large city, he may see on the wall a map with circles centering at the city and showing the maximum time that the traffic manager considers it reasonable for a carrier to consume in receiving, inspecting, billing, certifying, loading, transporting and delivering freight to its destination. He may note in the files of the office innumerable letters to the carriers complaining bitterly of failures to meet this time schedule. The carriers cannot meet the demands of these gentlemen and at the same time limit to one or two miles per hour the speed at which their cars are coupled.

Mr. Dauch is known to be one of the largest manufacturers of a superior type of the shipping containers frequently referred to as "substitute packages." It is the author's belief that containers of his type have a large and permanent field for usefulness. There are natural limits to this field, however, and the sooner these limits are specified by some competent authority, the better it will be for the success of such packages.

If this Society decides to appoint a committee to cooperate with other interested parties in this important work, it is predicted with confidence that due consideration will be given to all facts that affect an equitable distribution of the burdens that must be borne to improve present conditions. The author's recommendation that such a committee be appointed ought to be conclusive evidence of his advocacy of such a distribution.

SUGGESTIONS AS TO STANDARD SPECIFICATIONS TO PROMOTE EFFICIENCY AND SAFETY IN EXPLOSIVES USED IN BLASTING.

By C. P. Beistle.

The necessity for a standard specification for explosives varies according to the class of the commercial products offered to the consumer of explosives. While a large number of different kinds of explosives are manufacured, it is evident from a superficial observation of the industry that the great bulk of commercial blasting explosives used in this country is either black blasting powder or dynamite. Black blasting powder wherever made is practically uniform in composition and any variations in efficiency must be due to variations in the degree of intimacy of mixing of the ingredients, or the density of the finished powder.

As is well known, dynamites are made containing varying percentages of nitroglycerin, and the strengths of these dynamites vary with the nitroglycerin content. As nitroglycerin is a definite chemical compound, and most of the other ingredients are in common use by the different manufacturers, the relative efficiency of different dynamites can be determined approximately by a chemical analysis of the explosives.

Aside from the above-mentioned classes of explosives, there is a smaller production of material utterly different in composition, and a constant exploiting of new explosives of the most varying types. In considering these explosives a standard specification is desirable to learn their relative strength, efficiency and safety, as compared with the older and better known explosives.

Efficiency.

While explosives depend for their value on the strength and quickness of the explosion, their efficiency does not necessarily vary directly with these qualities. In considering

efficiency of an explosive, the conditions under which it is to be used are of the utmost importance, as the most diverse qualities are required in different applications.

The principal element in the efficiency of an explosive is the effective strength. According to a recent paper by A. M. Comey and F. B. Holmes,[1] this is best determined by the use of the Ballistic mortar. The mortar described by them is a steel mortar weighing about 450 lb. with a bore $4\frac{7}{8}$ in. in diameter and 5 in. deep; and a chamber behind 2 in. in diameter and 4 in. deep. A cylindrical shot fits the mortar closely. Ten grams of the explosive are used in this test, the charge being exploded with a blasting cap. The mortar is suspended as a pendulum and the angular deflection caused by the recoil is accurately measured. This amount of the recoil is compared with that produced by an equal weight of a standard explosive, such as a 40-per-cent dynamite. The results obtained by this test are accurate, and not affected by the rate of detonation.

The rate of detonation, while generally of less interest than the strength, is of great importance for certain uses. The method of Bichel is commonly used for this purpose. In this method a metal tube $1\frac{1}{2}$ in. in diameter is filled with cartridges of the explosive placed end to end. The tube is used in different lengths at different testing stations. A blasting cap is placed in one end of the tube, and electric wires through each end. The interval of time between the breaking of these two wires is a measure of the rate of detonation and is readily registered and measured on a standard chronograph. Some explosives will not communicate a detonation through a line of cartridges $1\frac{1}{4}$ in. in diameter, and their rate of detonation must be tested with a $1\frac{3}{4}$-in. cartridge placed in a 2-in. metal tube.

Explosives that require the use of $1\frac{3}{4}$-in. cartridges to propagate an explosion are naturally less efficient for many purposes, owing to the greater costs of drilling and general liability to miss fire.

Certainty of detonation is of obvious importance to the efficiency of any explosive. As suggested above, for most uses

[1] Original Communications, Eighth International Congress of Applied Chemistry.

an explosive should be capable of propagating an explosion through a line of $1\frac{1}{4}$-in. cartridges. It is also desirable for practical purposes that an explosive should be of such nature that the addition of small amounts of moisture will not render it incapable of detonation, nor that changes of density, such as may occur in tamping an explosive, will cause similar effects.

To test the effects of moisture, the explosive may be intimately mixed with varying proportions of water, 1, 2, 3, and 5 per cent respectively, then placed in cartridges, and action observed when a blasting cap is exploded in the cartridge.

Certain explosives when strongly compressed become so much less sensitive to detonation that the ordinary blasting cap does not explode them. It is suggested, therefore, that explosives be tested as to liability to detonation when under varying degrees of pressure.

The density of an explosive is of interest, as this element determines the weight of explosive that can be introduced into a certain drill hole. The apparent specific gravity, or the gravimetric density of the cartridge of explosive, is the value to be determined. The method used by the Bureau of Mines for determining this apparent specific gravity is to determine the volume of the cartridge by the use of dry sand.

Resistance to moisture is of greater or less importance according to the use to which the material is to be put, and the climate in which it must be used and stored. Ammonia dynamites are largely used in this country, in spite of the fact that they readily absorb moisture, and suffer consequent deterioration. It is suggested that the cartridges of explosive be exposed to a saturated atmosphere at a temperature of 95° F. for two months and the gain in weight of the cartridges be noted. In giving consideration to this point, due weight must be given not only to the amount of moisture absorbed, but to the effects of this moisture on the explosive qualities.

The cost of an explosive must be considered in determining the commercial efficiency. This cost should be the cost per pound of the material at the point of application. In this cost should be figured the cost of the detonators or blasting caps required for its use.

SAFETY.

The risks in the transportation and use of explosives are those due to the possibility of accidental explosion from various causes. These hazards may be due to external causes, such as impact, friction, detonation, fire, or heat; or to internal causes, such as exudation of nitrogylcerin or other explosive ingredient, or chemical instability.

The sensitiveness to impact is determined by subjecting small portions of the explosive to the impact of a falling weight. Various apparatus are used for this purpose, and although the apparatus is usually simple the results are often subject to great fluctuations. The apparatus used by the Bureau of Explosives for the purpose, consists of a small steel die with a hole drilled through it exactly 0.2 in. in diameter; a disk of the explosive 0.02 in. thick is held between two hardened steel cylinders fitting closely into the die and receiving the impact of an 8-lb. weight through a hardened steel piston. The weight is dropped various heights and the least drop causing the explosion of the material under test is noted.

To obtain concordant results on this or any other impact test it is requisite that a uniform degree of hardness of the working parts be obtained; that the faces of the two surfaces of the impact apparatus be parallel and in uniform condition of smoothness; and that the moisture content of the explosive be uniform. Owing to the above mentioned chances of variation the results of different apparatus or laboratories are not readily comparable with each other.

The methods of determining sensitiveness to friction are not commonly as satisfactory as the impact tests. The method used by the Bureau of Explosives is the same as the impact test, except that the sample of explosive is confined between a hardened steel plunger and a disk of emery paper. The test made in this way introduces an element of impact together with the friction. The Bureau of Mines has devised a test which subjects the explosive to friction without impact. The apparatus consists of a heavy iron pendulum, about 10 ft. long, swung from a suitable frame; so that a shoe on the lower extremity of the pendulum comes exactly tangent to a horizontal metal plate at the lowest point of its swing. The explosive to be

tested is spread on the horizontal plate where it is subject to the friction of the shoe on the swinging pendulum. The practical value of the results obtained by the apparatus is limited, owing to the fact that sensitiveness to friction varies according to the nature of the friction surfaces; also, in the practical handling of explosives impact and friction are liable to act at one and the same time and between the most diverse surfaces. For example, nitroglycerin explosives are not liable to explosion by friction of wood on wood, while certain chlorate explosives may be ignited or exploded by such friction.

The sensitiveness to impact and friction as directly determined by apparatus do not of themselves show the degree of safety of an explosive. An important point also to be considered at the same time is the ease of communication of the explosion to that portion of the explosive adjoining the point subject to friction or impact, as the explosion of only that portion under impact is of itself trivial unless extending throughout the mass. The sensitiveness to detonation is measured by placing cartridges end to end either suspended in the air or laid on the ground and noting to the maximum distance at which the detonation of one will cause the detonation of the other. In subjecting various explosives to this test a standard size cartridge must be employed.

The ease of ignition of an explosive depends to a large degree on its physical condition, rather than on the exact temperature of ignition. For example, black powder which has a temperature of ignition of approximately 280° C. is more liable to accidental ignition by flame or spark than is dynamite with an ignition temperature of 170° C. This is due to the fact that the black powder is a hard dry powder and liable to be in a very finely divided condition, while the dynamite is a plastic mass of coarse texture. More important than the relative ease of ignition is the effect of applying external ignition. This may be a deflagration accompanied by intense flame, a detonation, or merely a slow combustion, while the external flame is applied, and which ceases on the withdrawal of the external source of flame or heat. These different actions under fire or heat are characteristic of different types of explosive. From the standpoint of safety there is little preference between the explosives

that deflagrate and those that detonate when exposed to fire. Those that only burn slowly are of course the safest. It should be mentioned, however, that there is measure of uncertainty as to the action of burning explosives and some very destructive and fatal accidents have taken place with supposedly "safe" explosives; such accidents sometimes resulting from the lack of precautions owing to the supposed immunity from risk.

The internal sources of risk in an explosive are exudation (where the explosive contains a liquid explosive ingredient) and instability.

Exudation may take place owing to use of insufficient or improper absorbent in the explosive, or through deterioration of the explosive, by absorption of moisture, in storage or elsewhere. It is the object of exudation tests to determine if the liquid ingredient is liable to separate under service conditions of transportation and storage. Two tests have been found of value for this purpose:

1. The cartridge of explosive is placed in a vertical position in an oven heated to a constant temperature of 40° C. for six days, and any dripping from the cartridge is noted.

2. Ten grams of the explosive are placed on a perforated fiber disk in a glass tube having a cross section of 1 sq. in. This tube is placed in a centrifuge so that the disk is at a distance of 7 in. from the center. The centrifuge is revolved at a rate of 600 revolutions per minute for one minute and the amount of exudation is determined by the loss of weight of the dynamite.

It has been found that dynamites showing leakage on the 40° C. test generally show a loss of 3 per cent or more on the centrifugal test; to allow a reasonable margin of safety all dynamites when first made should show a centrifugal test of 1.5 per cent or less. Owing to differences in the absorptive qualities of the wood pulp and other absorbents used, and also to the variations in the viscosity of the nitroglycerin on account of the addition of other compounds for the purpose of lowering the freezing point, it is impracticable to specify the amount of absorbent for a given grade of dynamite.

The stability of explosives is that property which enables them to resist decomposition or deterioration under the conditions of storage. Instability is a very serious fault, as it not

only impairs efficiency but is liable to cause spontaneous ignition or explosion. The possibilities of instability and the cause and nature of the decomposition occurring where instability is possible, vary according to the composition of the explosive. With black powder no instability is possible and the only deterioration liable to occur is from moisture. Explosives containing nitroglycerin are liable to instability if the nitroglycerin is not thoroughly purified; but owing to the ease of purifying and the general use of the well-known methods of purification, the actual risk from the instability of nitroglycerin explosives is considered negligible. The purification of nitrocellulose and nitrostarch is more difficult, and hence there is greater need of stability tests on such materials. With chlorate explosives, even with pure ingredients, there are certain combinations that are inherently unstable and hence chlorate explosives require a stability test. The most widely used and one of the oldest is the Abel test or potassium iodide starch test. In this test a piece of paper impregnated with a uniform amount of potassium iodide and starch is moistened with a mixture of glycerin and water and placed in a corked test tube with a weighed quantity of the explosive; the tube is then partially immersed in a water bath at 65° or 71° C., and the time required for the appearance of a brown line on the test paper is noted.

This test is simple and has been applied to almost all classes of explosives, but in many instances there is no relation between the test and the actual stability of the material being tested. For nitrostarch explosives it has been found entirely unreliable, and such explosives are now tested by the Bureau of Explosives, and by the manufacturers, by subjecting small samples, approximately 0.5 gram, to a temperature of 100° C. for 24 hours and determining the loss of weight. The accurately weighed sample is placed in an unstoppered glass test tube 3 by $\frac{3}{8}$ in. Explosives that ignite in this test in less than 24 hours are considered deficient in stability. In testing chlorate explosives it has been the practice in the Bureau of Explosives laboratory to place a sample of the explosive moistened with distilled water in an oven heated to 100° C. for 48 hours and observe the results as to production of ignition; or if no ignition is produced, to note the production of acidity and reduction of

the chlorate to chlorides. A chlorate powder under this test should not ignite nor become strongly acid, or undergo much reduction to chloride. It has been found as a result of these tests that mixtures of sulphur and chlorates, or mixtures of ammonium salts and chlorates are unstable.

Owing to the lack of uniformity of methods of stability tests, an "International Commission for the Unification of the Testing Methods on the Stability of Explosives" has recommended the following test for all types of explosives:

"Two samples (10 grams each) of non-desiccated explosives are put into a glass capsule fitted with a cover (that cover being simply put over the capsule) and having a diameter of 35 mm. and a height of 50 mm. The samples are then put into a stove heated to 75° C., where they remain for 48 hours. No decomposure nor notable modification in aspect or smell must have to take place. The azotized explosives must let out no rutilant vapors."

Whether the above method will be adequate to determine the stability of all the explosives used in this country can not be definitely stated without investigation, as so far as known it has not been used to any extent here.

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